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Identification of Soils on Firefighter Turnout Gear from the Philadelphia Fire Department

Tabitha N. Huston
University of Kentucky, tabitha.nicole.huston@hotmail.com

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Tabitha N. Huston, Student

Dr. Elizabeth Easter, Major Professor

Dr. Scarlett Wesley, Director of Graduate Studies

IDENTIFICATION OF SOILS ON FIREFIGHTER TURNOUT GEAR FROM THE PHILADELPHIA FIRE DEPARTMENT

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture
at the University of Kentucky

By

Tabitha Nicole Huston

Lexington, Kentucky

Director: Dr. Elizabeth Easter, Professor of Merchandising, Apparel and Textiles

Lexington, Kentucky

December 12, 2014

ABSTRACT OF THESIS

IDENTIFICATION OF SOILS ON FIREFIGHTER TURNOUT GEAR FROM THE PHILADELPHIA FIRE DEPARTMENT

The purpose of this research was to identify the composition of soils on firefighter turnout gear from the Philadelphia Fire Department and to determine which soils contain hazardous materials. The objective of the research was to identify the composition of soils remaining on the firefighter turnout gear to enable the industry to design an effective cleaning procedure for removal of soils. A pilot study was conducted on hoods from the Philadelphia fire department to evaluate the test methods that would be used to identify the composition of soils. Soils that had been identified from previous studies were targeted in the analysis of the extraction of the samples removed from the hoods. Samples were removed from areas of the coats and pants where dermal absorption is reported as high areas of skin absorption, including areas in the neck, armpit, crotch and wrist locations.

KEYWORDS: Turnout Gear, Firefighter, Soils, Hazardous Materials, Philadelphia

Tabitha Nicole Huston

December 12, 2014

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By

Tabitha Nicole Huston

Dr. Elizabeth Easter

Director of Thesis

Dr. Scarlett Wesley

Director of Graduate Studies

December 12, 2014

Date

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"All fires generate an enormous number of toxic combustion products, including known and possible carcinogens, long-lived free radicals, and particulate matter. Smoke particles may serve as vehicles for absorbed volatile organic compounds. Peak exposures to some carcinogens may be very high, notable for benzene, 1,3-butadiene, and formaldehyde. Firefighters may be exposed at different levels depending on crew assignment, tasks and/or the time spent at fires" (Thomas, 2010, p. 556). Firefighters are working daily in high temperatures risking their lives while battling raging infernos (Mustane, 2013). These brave men and women are unremittingly being exposed to potential hazards during fire suppression or emergency situations (Smith, 2011). The National Fire Protection Agency (NFPA) estimated that over 19,200 exposures to hazardous conditions occurred in 2012, such as asbestos, radioactive materials, chemicals and fumes (Karter, 2013). These conditions can cause significant soiling to the firefighter gear.

According to NFPA, soils/soiling is defined as "the accumulation of materials that are not considered hazardous materials, body fluids, or CBRN terrorism agents but that could degrade the performance of the ensemble or ensemble element" (National Fire Protection Association [NFPA], 2014, p. 11). NFPA 1851 defines hazardous materials as "substances that when released are capable of creating harm to people, the environment, and property" (National Fire Protection Association [NFPA], 2014, p. 10). The hazardous materials not only present potential harm during the time a firefighter is engaged in fire suppression or emergency situations, but also post use, or until the contaminated garments are decontaminated or the hazardous materials are removed (Stull, 2007). Although routine cleaning procedures are recommended to ensure the appropriate care and maintenance of firefighter turnout gear, the procedures are often ignored, leading to increased exposure of hazardous materials and cross contamination (Stull, 2007).

Firefighters rely on their turnout gear to protect their bodies from extreme temperatures and hazardous materials (Jorgensen, 2002). NFPA 1971: Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting sets minimum requirements for elements of the turnout gear including coats, trousers, on-piece suits, helmets, gloves hoods, and footwear (NFPA, 2013). This standard specifies the technical design of the turnout gear, recommended testing procedures and performance requirements as well as information on new developments that have been made in the ensemble. With the high costs of professional cleaning services some fire departments disregard NFPA 1851 (NFPA, 2014). In 2001, NFPA established standard NFPA 1851: Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting. The standard defines the requirements for the care and maintenance by addressing the selection, cleaning, inspection and repair of turnout gear (NFPA, 2014). The standard is utilized by some fire departments across the country, but some departments do not stress the need for how frequent the firefighter gear is to be inspected and cleaned (Stull, 2007). By disregarding NFPA 1851 and NFPA 1971, the risk of gear malfunction and unnoticed chemical contamination adds unnecessary additional risk for firefighters responding to already hazardous emergency situations (Stull, 2007).

In order for a firefighter to protect and rescue others, they should follow NFPA 1851 recommended standards and/or procedures. Firefighters should routinely inspect and thoroughly clean their turnout gear. When firefighters ignore these standards, they are not only endangering their own lives by using damaged and contaminated gear, but also the lives of their families and co-workers.

Problem

Structural fires have the potential to release substances that are considered toxic and possibly carcinogenic (Thomas, 2012). Previous studies have shown that the soils present on turnout gear increases the risk of several types of cancer, respiratory problems and biological contamination ("Gear Cleaning Services," 2012). Some of these soils contain benzene, polychlorinated phenols, polycyclic aromatic hydrocarbon, 3-butadiene, and formaldehyde (Thomas, 2012). In particular, these substances are concerns for increased cancer risk in humans (Thomas, 2012). As the use of synthetic polymers in building materials and interior furnishings increases, the burning of these materials creates concerns that they may release large amounts of both heat energy as well as highly toxic substances (Thomas, 2012). During combustion, many of the carcinogenic products identified in structural fires are considered volatile organic compounds (Thomas, 2012).

Many firefighters, rookies and veterans alike, often view their turnout gear a status symbol (Jorgensen, 2002). Worn and soiled turnout gear gains a higher respect from peers, reflecting the survival of dangerous tasks and fires (Stull, 2007). But soiled turnout gear may contain hazardous chemicals or toxins which are removed when cleaned according to procedures recommend by the NFPA 1851 standard (Zender, 2008). Each layer of turnout gear should be carefully inspected, treated as if it is heavily soiled and cleaned individually to prevent transfer of hazardous chemicals or toxins (NFPA, 2013).

Researchers have expressed concern for the firefighter's short and long-term exposure to soiled turnout gear and noted that this exposure may contribute to an increase in the diagnosis of cancer in some firefighters (Thomas, 2012). If adequate cleaning of firefighter gear is not maintained soiled gear increases the risk of dermal absorption, which may lead to short and long term health issues. Even when professional cleaning services are utilized to clean firefighter turnout gear, many soils may remain (Stull, 2007). Although specialized equipment is recommended for adequate cleaning and prolonging the life of this gear, the professional cleaning services recommended by NFPA can be very costly for fire departments (Stull, 2007). In some cases, adequate cleaning of the gear is cost-prohibited and therefore is not implemented by the departments (Jorgensen, 2002).

According to NFPA 1851, contamination is defined as "the process by which protective clothing or equipment has been exposed to hazardous materials or biological agents." Precautions should be taken when handling soiled turnout gear as the soils may contain hazardous chemicals or toxins, which will increase the health risk of the fire fighter (Stull, 2007). In order to develop an effective cleaning process one must identify the composition of the soils on turnout gear and determine if the soils do contain hazardous materials.

Purpose

Prior research has identified that potentially hazardous materials remain embedded in firefighter turnout gear after following standard cleaning procedures (Stull, 2007). The purpose of this research was to identify the composition of soils on firefighter turnout gear from the Philadelphia Fire Department and to determine which soils contain hazardous materials. After the composition of the soils has been identified, the researcher used a risk assessment calculation derived from the Environmental Protection Agency (EPA) to determine if the soils include hazardous materials that create a risk of health problems for firefighters. Specific laundering instructions and standards are recommended for the removal of soils on turnout gear (NFPA, 2013). Before designing an effective cleaning procedure for firefighter turnout gear, the soils should be identified as well as the potential health risk of these soils. If one identifies the potential risks of the soils and the levels of exposure, an effective cleaning procedure can then be implemented to reduce potential health risks. By following an effective and efficient way to adequately clean turnout gear will benefit the fire fighters and results in a decrease in carcinogens and toxins remaining on the turnout gear that cause life-threatening disease.

Research Objectives

The objective of the research was to identify the composition of soils on the firefighter turnout gear from the Philadelphia Fire Department. A quasi-experimental design was implemented to analyze quantitative data that reflects the soil levels.

1. To visually identify the areas of heavy soiling on turnout gear (coats and pants).
2. To evaluate the composition of soil using analytical lab procedures.
3. To identify the location of potentially hazardous materials on soiled firefighter turnout gear in the context of the areas where dermal absorption is high.
4. To determine the dangers of exposure to the hazardous materials by evaluating the quantity and comparing this quantity to the recommended exposure limits.
5. To evaluate results to determine if they correlate to the use of the turnout gear.

Research Questions

In order to meet the research objectives, the following research questions were examined:

1. What are the areas of heavy soiling on used turnout gear?
2. What are the soils found on the firefighting turnout gear?
3. What are the locations on the firefighter turnout gear in the context of areas where dermal absorption is high and are considered hazardous and are potentially harmful to the firefighter?
4. What are the exposure limits of the hazardous materials?
5. Do the results correlate to the use of the turnout gear?

Justifications

The Executive Chief of Health and Safety at Philadelphia Fire Department, Henry Costo, requested that research be conducted to identify the soils on firefighter turnout gear at the Philadelphia Fire Department due to the increased health problems in the fireman and retirees. The Kingsland study, completed at the University of Kentucky in 2003 identified soils on the Philadelphia Fire Department's firefighter gear that were thought to be of concern for the firefighters health. Costo expressed his concern for the potential hazardous materials that the firefighter are exposed to and questioned whether they would be identified as carcinogens.

NFPA 1851 recommends cleaning turnout gear after every single exposure to fire suppressions or an emergency situation in order to prevent prolonged exposure to soiled gear (NFPA, 2013). By identifying the hazardous materials within these garments and stressing the need for an effective laundering process among fire fighters they are less likely to delay effective cleaning procedures. Each time a garment is not thoroughly cleaned, the probability of severe health risks increases from the exposure of hazardous contaminants and likelihood of cross-contamination spreading onto skin.

Even after following the NFPA's 1851 recommended cleaning procedures, soiled gear may not be completely decontaminated, requiring a more profound cleaning cycle to eliminate the risk of harm (Stull, 2007). However, the cleaning cycle may require unusually high water temperatures or detergent levels that could potentially break down the composition of the turnout gears fabric. Disintegrated fabric, even if minor, may not have the full, originally intended protection.

Limitations

The sample size of turnout gear was limited due to selection criteria for the gear to be in service at least three to five years, cleaned at least once per year by a professional cleaning service and showing visual signs of heavily soiled areas. The researcher had no control as to what garments are received. Sample data was not collected randomly; the turnout gear was supplied by the Philadelphia Fire Department and selected based the number of years in use along with the amount of wash cycles the turnout gear went through. The gear that was selected for this study will be solely left up to the decision of the Philadelphia Fire Department. Due to funding, the sample size may not be a significant sample size. This may have an effect on the end results of the study, preventing the research to obtain an extensive reading on the soiled sample areas taken from the turnout gear. The sample size may affect how many specimens can be taken from each set of turnout gear, which may also affect the size of the specimen.

Assumptions

The information collected on the soiled firefighting turnout gear was assumed to be representative of the turnout gear from the Philadelphia Fire Department. The areas on the turnout gear where specimens were taken are areas of increased dermal absorption. The areas include the wrist, crotch, armpit, and collar (Maibach, 1971). It is assumed that these areas allow direct dermal absorption into the bloodstream, creating health problems for those whom are affected.

Chapter Two

Review of Related Literature

The purpose of this research was to identify the composition of soils on firefighter turnout gear from the Philadelphia Fire Department and to determine which soils contain hazardous materials. The review of literature provides relevant information regarding (1) The Firefighters' Hazardous Work Environment, (2) Protective Clothing in the Firefighting Environment, (3) Soiled Turnout Gear, (4) Hazards of Soiled Turnout Gear, (5) NFPA 1851, (6) Care and Maintenance of Firefighting Turnout Gear. This review of literature will summarize research findings that identify soils and contaminants found on firefighter turnout gear and address the dangers of hazardous materials associated with soiled firefighter turnout gear. Research on the care and maintenance of turnout gear will also be reviewed.

Firefighters' Hazardous Work Environment

The hazards associated with fighting fires can be related to the type of fire and there are two types of fires: outdoor and structural. The majority of firefighters spend most of their time battling structural fires (Karter, 2013). NFPA defines structural firefighting as, "The activities of rescue, fire suppression, and property conservation in buildings, enclosed structures, vehicles, marine vessels, or like properties that are involved in a fire or emergency situation," (National Fire Protection Association, p. 11, 2013). Structural firefighting poses numerous hazards to the firefighter including but not limited to high heat flux temperatures, steam, smoke and biological and chemical contaminants. The potential hazards of structural fires continue to change due to the changes in furnishings, roofing material, insulation, carpets, paints, and other construction materials (TRI/Environmental, Inc., 1994). The burning of these materials, may release hazards into the fire environment that soil the protective clothing and if contacted with the skin, an increased risk of dermal absorption occurs (Smith, 2011).

Today's firefighters will spend a considerable amount of time in the "post fire" environment (Stull, 2006). This environment includes, but is not limited to, victim recovery, salvage and overhaul, origin and cause investigation, and criminal investigations (Stull, 2006). In 2012, the NFPA estimated that 69,400 firefighter injuries occurred in the line of duty (Karter, 2013). The NFPA estimates that in addition to firefighter injuries, there were 8,150 exposures to infectious diseases and 19,200 firefighters were exposed to hazardous conditions such as, asbestos, radioactive materials, and chemicals (Karter, 2013). The number of incidents that firefighters respond to each year continues to grow. When a firefighter is in the line of duty their turnout gear may be exposed to the byproducts of combustion which has the potential to soil or contaminate the gear. Research suggests that airborne hazards associated with the post-fire environment are much greater than what has been previously understood (Stull, 2006). Post-fire environments present a broad spectrum of chemical hazards, including gases, vapors and particulates, and these hazards aren't limited to just the immediate fire area (Performance Apparel Markets, 2012).

Most fire departments have adopted requirements for ample protection during structural fires. Studies have shown that once the outer shell of the turnout gear has been exposed to extreme temperatures for long periods, ranging from 150˚C to 250˚C, the properties of the protective gear begin to show significant loss of thermal protection (Reed, 2003). All fires generate multiple products of combustion or incomplete combustion, including smoke, particulate matter, as well as volatile organic compounds. As noted in the International Agency for Research on Cancer Monograph (IARC), 2010 smoke from fires is a complex mixture of suspended liquid and solid matter, gases, and vapors from the combustion or pyrolysis of materials (Thomas, 2010). A large number of these substances are considered toxic and carcinogenic including benzene, polychlorinated phenols, polycyclic aromatic hydrocarbon, 3-butadiene, and formaldehyde (Thomas, 2010). All types of fires release potentially toxic or hazardous substances but, with the increased use of synthetic polymers in building materials and furnishings, there is concern that the burning of new materials might release large quantities of highly toxic substances (Austin, et.al. 2001b).

Protective Clothing in the Firefighting Environment

The function of firefighter's protective clothing is to form a physical barrier between the wearer and their environment (Performance Apparel Markets, 2012). Historically, the firefighter's protective clothing consists of rubber coats that hit past the knee and pull-on boots. With the development of protective fabrics, manufacturers of turnout gear have utilized these fabrics to create a garment that better protects the firefighter from the hazardous environment. NFPA 1971, Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting, 2013 edition, defines the structural firefighting protective garment as “the coat, trouser, or coverall element of the protective ensemble” (NFPA, p. 11, 2014). The coat and trousers of the protective garment are made up of three layers: outer shell, moisture barrier and thermal liner. The outer shell fabric provides flame resistance and is considered the first line of protection against flames and heat (Horrocks, 2005). This layer is typically made of Kevlar®, Nomex®, or PBI fabrics, in various combinations (Firefighter Gear - The First Line of Defense, 2013). Some manufacturers of firefighter turnout gear use Kevlar® and Nomex® as a blended fabric, as well as PBI® and Kevlar®, whereas others focus solely on Nomex® as a standalone fabric. The water resistant middle layer, referred to as the moisture barrier, provides protection from intrusion of water and other liquids, such as blood borne pathogens. The inner thermal liner layer provides protection against radiative, convective, and conductive heat transfer. This nonwoven layer increases thermal insulation by trapping air within its layers. The three layers of protective clothing that make up a set of turnout gear provide the firefighter with adequate protection against heat, water and particulates (Stull 2006).

In order for the protective garment to be considered an effective barrier between the wearer and the soils and contaminants the wearer may come in contact with, it must demonstrate the ability to resist penetration, permeation, degradation, and abrasion (Performance Apparel Markets, 2012). Penetration is defined as “the act of going through or into something” such as the pores of the turnout gear barrier material (Merriam-Webster, 2014). Permeation is the process by which a “potentially hazardous chemical moves on a material on a molecular level” (Firefighter Gear – The First Line of Defense, 2014). The permeation rate can depend on the type, state, concentration, exposure time, and temperature of the contaminant and is not apparent to the user of the gear (Firefighter Gear – The First Line of Defense, 2014). Degradation is defined as the “change in the physical state of the material as a result of the contact with soils and contaminants” (Corbett, p. 794, 2009) Abrasion of the protective fabrics is also a concern because if the material has been flexed or rubbed, then the fabrics’ ability to resist the penetration of soils and contaminants can diminish (Stull, 2006).

Woven fabrics, in general, are not considered to be suitable for protection against soils and contaminants at the molecular level (Performance Apparel Markets, 2006). However, woven fabrics made of Nomex® and Kevlar® that makes up the moisture barrier are constructed and coated with flame retardants to be highly effective for the barrier materials used in firefighter turnout gear.

Soiled Firefighter Turnout Gear

The cumulative build-up of soils on firefighter turnout gear is often considered a symbolic badge of honor that displays their acts of bravery when responding to emergency situations (Sesko, 1991). Firefighters view the outward appearance of their turnout gear as a way to boast their achievements while in the field. This build-up of soils, and the chemicals they contain, however, poses a large health risk to the wearer. Although some soils and contaminants identified on turnout gear may take years to result in major health issues, they still create an extremely dangerous situation for the firefighter, but also to the family of the firefighter or anyone who comes in direct contact with the gear (Smith, 2011).

In 1996, Jeffery Stull completed a study on “Determining the Effects and Effectiveness of Cleaning Procedures for Removing Fire Ground Contaminants from Firefighting Protective Clothing”. In this study, he used three different perspectives to examine the effectiveness of laundering methods for firefighter turnout gear. Those included establishing the nature and concentrations of contaminants found on used firefighter protective clothing, the efficiency of cleaning or decontamination methods, and measuring the degradation effects of the cleaning and decontamination methods (Stull, 1996). This study examined several sets of turnout gear that were evaluated for different levels of chemical contamination (Stull, 1996). First, Stull selected the specimens that appeared most visually soiled for a destructive analysis that included searching for semi-volatiles, polychlorinated biphenyl’s (PCB’s) and metals (Stull, 1996). Next, Stull selected six different methods to represent a range of cleaning methods, including agents and processes (Stull, 1996). Finally, Stull examined air-drying, dryers, washing temperatures, and drying temperatures. A total of 4 drying conditions and 2 laundering conditions were evaluated (Stull, 1996). Stull’s results found significant amounts of heavy hydrocarbons and polynuclear aromatics along with high concentrations of heavy metals (Stull, 1996). Many of the identified contaminants found in Stull's study have been identified as suspected carcinogens (Stull, 1996).

Worn and damaged gear provides firefighter with an honorary, tangible symbol of evidence for their past calls. However, the soiled turnout clothing is proven to reflect less radiant heat when the material is saturated with contaminants (Stull, 1996). Many particulates can cause potential health hazards and significant dangers from depositing themselves on the protective equipment, turnout gear, and onto the skin surface (Stull, 2006). Soiled and contaminated turnout clothing can degrade over time and begin to reflect less radiant heat (Performance Apparel Markets, 2012). When the turnout gear becomes saturated with hydrocarbons, the materials begin to absorb rather than reflect the radiant heat, which provides less thermal insulation for the firefighter (Stull, 2006). The firefighter gear will also conduct electricity and can ignite when heavily contaminated with hydrocarbons. Many fire departments do not have a clear understanding of how to handle these hazardous situations, especially when dealing with decontamination and laundering the clothing ensembles (Stull, 2006). NFPA 1851's first edition was published in 2001 and developed as a companion for NFPA 1971. The NFPA 1851 standard was written to help departments evaluate the risk that emergency responders face and the need for protective clothing (NFPA, p. 1, 2014). The NFPA 1851 standard set requirements for several areas of the protective ensemble including cleaning, inspections, decontamination, and repairs (NFPA, p. 1, 2014). The soiled protective clothing can be contaminated in various situations, whether it is from a structural fire by direct or indirect contact, by responding to a fatal car accident, chemical spill or cross-contamination among other firefighters turnout gear. Fire departments must abide by their state laws, many of which have adopted the NFPA recommendation which mandates the departments to regularly launder the turnout gear.

In 2003, Cassandre Kingsland completed a study on the cleaning and care of turnout gear titled, "Analysis of Soil Removal from Firefighting Turnout Gear: An Evaluation of Care and Maintenance Procedures". The purpose of this research was to identify the type and concentration of soils found in the firefighting turnout gear and to examine the laundry practices of fire departments (Kingsland, 2003). This research included two phases, a field study and a laboratory phase. The field study examined the different types and levels of soils that were extracted from the firefighting turnout gear after routine use, after cleaning occurred within the fire department, and after a cleaning cycle within a laboratory (Kingsland, 2003). The laboratory cleaning procedures included preparing the fabric samples from the firefighter turnout gear and base loads, hand dosing the selected soils on the samples, laundering the samples and extracting the soils to measure the soil removal (Kingsland, 2003).

In Kingsland's study, the levels of contamination of turnout gear were identified according to the chemicals and carcinogens present on the samples. The sample of turnout gear in her study included turnout gear from the Philadelphia Fire Department along with eight other departments across the United States (Kingsland, 2003). The fire departments provided Kingsland with an assortment of soiled garments. The soiled garments were evaluated, cut in half vertically and half of the garment was washed using the fire department's routine cleaning procedure, and the other half was unwashed for laboratory analysis (Kingsland, 2003). The field study provided insight about the soils that were embedded in the turnout gear and allowed Kingsland to make the decision to hand dose the samples with selected soils from the field (Kingsland, 2003). There was a limited amount of gear for the field study. Specimens were cut from both the soiled and cleaned garments and then selected based on visual soiling. The researcher selected the most visually soiled areas for evaluation; therefore the specimens used in Kingsland's research may not represent the degree of soiling for the entire garment. Kingsland evaluated the gear before cleaning, after department cleaning, and after laboratory cleaning.

Three specialty detergents were selected for the study. These selections were based upon detergents that were in use at those fire departments where the samples had originally come from. The Philadelphia Fire Department was the largest department that participated in the Kingsland study. The fire department was said to have employed 2,320 fire fighters and protect a total of 135 square miles, at the time of the study. Thirty three percent of the runs from the Philadelphia Fire Department were fire emergencies. During this research study, Philadelphia's Fire Department did not clean their gear in house but sent their soiled turnout gear to a third party, professional cleaning service. Among the 32 total chemicals identified in the field study, the individual compounds that Kingsland focused on were as follows: Octicizer® (2-ethylhexyl diphenyl phosphate), Bis (ethylhexyl) phthalate, Di-n-octyl phthalate, and N-Octacosane (Kingsland, 2003). These compounds were selected because of the levels that were extracted from garments from the field before the laundering process (Kingsland, 2003).

The Firefighter Occupational Exposures (FOX) Project is an ongoing study that is being conducted on environmental chemical exposures in firefighters. The FOX study was organized in partnership with the University of California Irvine's Center for Occupational and Environmental Health (UCI COEH) and a Southern California fire department (FOX, 2013). A total of 101 firefighters were chosen for the study because of their likeliness to be exposed to many toxic chemicals in the performance of their duties (FOX, 2013). Information was collected via questionnaire along with blood and urine samples from the firefighters who are located in Southern California (FOX, 2013). The following chemicals are being monitored in the FOX study: Arsenic, Benzophenone-3 (Oxybenzone), Bisphenol A, Metals, Cadmium, Lead, Manganese, Mercury, Organophosphate Pesticides, Parabens, Perfluorochemicals, Phthalates, Polybrominated Diphenyl Ethers (PBDEs), PCB's, Triclosan, and 2,4-Dichlorophenoxyacetic acid (2,4-D) (FOX, 2013).

The results from the FOX bio monitoring study include the levels of detection of the following chemicals in the firefighters' urine samples: 2, 4-D, Bisphenol A, Triclosan, Methyl paraben, Propyl paraben, Mono-benzyl phthalate, arsenic, mercury, and cadmium (FOX, 2013). The results vary between firefighters routine questionnaires. The survey monitors the firefighters behaviors and exposure environments and raises awareness for additional research concerns. At this time, this study has not been completed but results are posted as they become available. The results to date are illustrated in Table 2.1. The limit of detection is the lowest level of a chemical that the laboratory can measure in the urine samples (FOX Biomonitoring, 2014). The detection frequency is reported as the percentage of study participants that have a measurable level of a chemical in their blood or urine (FOX Biomonitoring, 2014).

Table 2.1

Results to date - FOX Bio-monitoring Project

Compound	Geometric Mean (95% Confidence Interval)	Detection Frequency	Limit of Detection ug/kg
Triclosan	20.2	99.0%	0.5
Methyl paraben	46.9	98.2%	1
Bisphenol A (ng/ml)	1.58	1.94	0.2
2,4-D (2,4 Dichlorophenoxyacetic acid) (ug/L)	0.27	90.10%	0.05
p,p-DDT p,p dichlorodiphenyltrichloroethane (ng/g lipid)	1.34	4.0	0.005
p,p-DDE p,p-dichlorodiphenyldichloroethene (ng/g lipid)	177	100	0.009
3-PBA (3-Phenoxybenzoic acid) ug/L	0.54	98.0	0.05
TCPy 3,5,6 Trichloro-2-pyridinol (ug/L)	1.78	89.1	0.5
Arsenic (ug/L)	10.7	100	0.16
Mercury (ug/L)	0.46	100	0.052
Cadmium (ug/g creatinine)	0.15	69.7	Varies by creatinine level.
BDE 28 (2,4,4 Tribromodiphenyl ether) ng/g lipid	1.7	97	0.003

Table 2.1

Results to date - FOX Bio-monitoring Project (continued)

Compound	Geometric Mean (95% Confidence Interval)	Detection Frequency	Limit of Detection ug/kg
BDE 47 (2,2,4,4,6 Tetrabromodiphenyl ether)	32.2	99.0	0.038
BDE 99 (2,2,4,4,5 Pentabromodiphenyl ether)	6.19	90.1	0.017
BDE 100 (2,2,4,4,6 Pentabromodiphenyl ether)	5.68	98	0.005
BDE 153 (2,2,4,4,5,5 Hexabromophenyl ether)	15.4	100	0.005
PCB 66 (2,3,4,4 Tetrachlorobiphenyl) ng/g lipid	1.17	74.3	0.007
PCB 74	1.77	96	0.005
PCB 99	1.76	98.0	0.005
PCB 153	12.2	100	0.005
PCB 170	3.64	97	0.005
PCB 180	13.4	100	0.006
PCB 183	1.03	67.3	0.005
PCB 187	2.99	97	0.005
PCB 194	3.37	98	0.005
1- NAP (ng/L)	1150	100	25

Table 2.1

Results to date - FOX Bio-monitoring Project (continued)

Compound	Geometric Mean (95% Confidence Interval)	Detection Frequency	Limit of Detection ug/kg
2-NAP	2830	100	20
2-FLUO	153	100	20
3-FLUO	74.2	96.0	20
9-FLUO	247	100	37
1-PHEN	106	100	10
2-PHEN	59.6	100	10
1-PYR	77.5	95.1	20
DEHP diethyl hexyl phthalate (ug/L)	12.3	100	0.5
DOP dioctyl phthalate (ug/L)	1.88	98	0.125
BzBP Benzyl butyl phthalate (ug/L)	8.18	100	0.25
DBP Dibutyl phthalate (ug/L)	10.6	97	2.0
DEP diethyl phthalate (ug/L)	52.9	79.2	8.0

Table 2.2 compares the FOX biomonitoring data for Firefighters to the Center for Disease Control National Health and Nutrition Examination Survey (CDCNHANES) biomonitoring data of the general population. There were three PBDE substances (in bold) where the firefighters biomonitoring results were at least 20% higher than the general population biomonitoring data.

Table 2.2

Comparison of Fox Biomonitoring Data to General Population

Class	Chemical	Firefighters	NHANES
Pesticides	2,4-D (2,4 Dichlorophenoxyacetic acid) ug/L	0.27	<0.2
	p,p-DDT p,p dichlorodiphenyltrichloroethane (ng/g)	1.34	<7.8
	p,p-DDE p,p-dichlorodiphenyldichloroethene (ng/g)	177	235
	3-PBA (3-Phenoxybenzoic acid) ng/ml	0.54	0.33
	TCPy 3,5,6 Trichloro-2-pyridinol (ng/ml)	1.78	1.48
Metals	Arsenic (ug/L)	10.8	10.1
	Mercury (ug/L)	0.46	0.8
	Cadmium (ug/g creatinine)	0.15	0.23
polybrominated diphenyl ethers (PBDE)	BDE 28 (2,4,4 Tribromodiphenyl ether) ng/g	1.7	1.17
	BDE 47 (2,2,4,4,6 Tetrabromodiphenyl ether)	32.2	21.4
	BDE 99 (2,2,4,4,5 Pentabromodiphenyl ether)	6.19	5.28
	BDE 100 (2,2,4,4,6 Pentabromodiphenyl ether)	5.68	4.16
	BDE 153 (2,2,4,4,5,5 Hexabromophenyl ether)	15.4	6.8
Polychlorinated biphenyls (PCBs)	PCB 66 (2,3,4,4 Tetrachlorobiphenyl) ng/g	1.17	1.29
	PCB 74	1.77	4.06
	PCB 99	1.76	3.97
	PCB 153	12.2	20
	PCB 170	3.64	5.81
	PCB 180	13.4	16.1

Table 2.2

Comparison of Fox Biomonitoring Data to General Population (continued)

Class	Chemical	Firefighters	NHANES
Polychlorinated biphenyls (PCBs)	PCB 66 (2,3,4,4 Tetrachlorobiphenyl) ng/g	1.17	1.29
	PCB 74	1.77	4.06
	PCB 99	1.76	3.97
	PCB 153	12.2	20
	PCB 170	3.64	5.81
	PCB 180	13.4	16.1
	PCB 183	1.03	1.47
	PCB 187	2.99	4.3
	PCB 194	3.37	2.95
Polyaromatic Hydrocarbons (PAHs)	1- NAP (ng/g lipid)	1150	2660
	2-NAP	2830	3690
	2-FLUO	153	323
	3-FLUO	74.2	127
	9-FLUO	247	360
	1-PHEN	106	134
	2-PHEN	59.6	67.7
	1-PYR	77.5	108
Plasticizers	DEHP diethyl hexyl phthalate (ug/g)	12.3	27.2
	DOP dioctyl phthalate (ug/g)	1.88	2.21
	BzBP Benzyl butyl phthalate (ug/g)	8.18	5.59
	DBP Dibutyl phthalate (ug/g)	10.6	14.1
	DEP diethyl phthalate (ug/g)	52.9	84.8
	Bisphenol A (ng/ml)	12.3	1.94

Hazards of Soiled Firefighter Turnout Gear

During firefighter activities, firefighters may be exposed to chemicals and toxins that have been identified as hazardous materials due to their potential to cause various forms of cancer, respiratory issues, and cause skin irritation (NIOSH, 2013). Exposure to these potentially hazardous materials is not limited to the firefighter's health; it can play a role in affecting the families of the firefighters as well. Improper handling of contaminated turnout gear can result in cross-contamination among the household and workplace (Stull, 2006). This often happens in cases where volunteer firefighters toss their clothing in with the rest of the family's laundry (Stull, 2006).

A study in Australia showed that carcinogens were present on the firefighter's skin after the firefighter was in contact with simulated residential and industrial fires (Underwriters Laboratories Inc., 2010). Firefighters are more likely to be exposed to hazardous materials during the response to structural fires than during hazardous material incidents (Firefighter Cancer Support Network, 2014). Response teams often report to hazardous material incidents with an extreme level of caution, whereas structural fires are often treated in a manner of less monitoring for hazardous materials (Stull, 2014).

The University of Cincinnati conducted a study in 2012 on "Firefighter Cancer in the New Fire Environment". This study assessed the contribution of cancer and heart disease to death and diseases among firefighters, both those on duty and retired. Some risks that were addressed in this study included the possible health hazards from combustible products of synthetic materials, skin contamination that increases the risk of cancers, and effects of the absorption of chemicals that are deposited on the skin (University of Cincinnati, 2012). A total of 32 articles (gloves and hoods) used by firefighters from 19 fire stations were reviewed and the following health effects were found: multiple myeloma, non-Hodgkin's lymphoma, prostate cancer and testicular cancer (University of Cincinnati, 2012). Plasticizers were the main focus in this study but it also included alkyl phenols which are plastic additives that are known to interfere with reproduction and development in animals and polycyclic aromatic hydrocarbons which cause lung and skin cancer (University of Cincinnati, 2012). The preliminary conclusions of the study suggest that exposures to plasticizers during fire suppression may cause an increased risk of prostate cancer in firefighters (University of Cincinnati, 2012). Plasticizers and aromatic hydrocarbons were also identified in the firefighter turnout gear that was analyzed in the Kingsland study.

A study published by the National Institute for Occupational Safety and Health (NIOSH) in 2013 reported that firefighters are exposed to contaminants from fires that are known or suspected to cause cancer and health risks. The contaminants include combustible by-products such as benzene, asbestos and formaldehyde. Benzene is a natural constituent of crude oil and was also identified on turnout gear that was analyzed in the Kingsland study. The study focused on a sample population of 30,000 firefighters from three large cities including Philadelphia, San Francisco and Chicago. This study found that there were higher rates of cancers such as digestive, urinary and respiratory in the study population. The firefighters in this study's population also had a higher rate of mesothelioma that was reported two times greater than the United States population as a whole. The study suggested that due to the firefighters increased exposure to asbestos is a direct cause of mesothelioma, which is a known cause of this type of cancer.

Hazardous Materials. While many hazardous materials that are volatile can dissipate over time, the carbon based soot particles absorb vapors, trapping the volatiles and holding them on the surface of firefighter clothing and the skin (Stull, 2014). The chemicals that are trapped on the particles can migrate to the surrounding environment and can be in direct contact with the firefighters skin (Stull, 2014). Based on prior research, the following chemicals were identified in the Kingsland study as a concern for dermal absorption: N-Octacosane, Di-N-Octyl Phthalate, Octicizer® (2-Ethylhexyl Diphenyl Phosphate), and Bis (ethylhexyl) phthalate. Each chemical identified was found on turnout gear from the Philadelphia Fire Department. N-Octacosane is identified as a waxy hydrocarbon that is insoluble in water (EPA, 2014). Permeation through turnout gear can occur, so it is suggested that if this chemical comes in contact with the skin to remove the clothing immediately.

Di-N-Octyl Phthalate is a colorless plasticizer that has a mild odor (“Cameo Chemicals”, 2014). As a liquid, it can easily penetrate through fabrics and can produce mild skin irritation. Di-N-Octyl is often used in the manufacturing process of a variety of plastics and coating products. This compound is often used in carpet backing, floor tiles, cables, adhesives and medical tubing (Kingsland, 2003). Di-N-Octyl Phthalate has not been tested on humans for its ability to cause cancer but NIOSH reported that there is “reasonable basis for assuming relevance of these data for judging potential hazards to humans,” (NTP-CERHR expert panel report, 2000, p. 18). High or repeated exposure to this compound may affect the liver (“New Jersey Department of Health Services”, 2002).

Octicizer®, a trade name for 2- Ethylhexyl Diphenyl Phosphate, is identified as a pale yellow liquid that is insoluble in water and often referred to as organophosphates ("Cameo Chemicals", 2011). Organophosphates are susceptible to forming into highly toxic and flammable phosphine gases if they are in the presence of strong reducing agents, such as hydrides. The result of partial oxidation by the oxidizing agents can result in the release of toxic phosphorus oxides. This compound is a plasticizer and is combustible at a flash point of 435.2°F. Octicizer® may produce dangerous vapors and is considered harmful when ingested or inhaled ("EPA", 2014).

Bis(2-ethylhexyl) phthalate (DEHP) is a plasticizer commonly used to make polyvinyl chloride resins, cosmetic products, toys, teething rings, food containers and shower curtains as well as many other plastic products. This compound produces a poisonous gas in a fire and is dissolved easily in saliva and plasma ("United States of Environmental Protection Agency", 2013). The Kingsland study reports that the National Toxicology Program of the U.S. Department of Human Health and Services classified Bis (ethylhexyl) phthalate as a carcinogen and stated that exposure could occur though inhalation, ingestion, or dermal contact ("United States of Environmental Protection Agency", 2013).

NFPA 1851

NFPA began developing standards in the early 1980s to provide firefighters with ample protection and to address the environments in which they enter as first responders. The NFPA developed NFPA 1851, *Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*. NFPA 1851, 2014 edition contains vital information and procedures on how to inspect, clean, and repair firefighter's protective clothing. There are specific guidelines that should be followed by all fire departments to ensure the safety of each individual coming into contact with the turnout gear. NFPA 1851 was mandated by the Federal Occupational Safety and Health Administration (OSHA); this standard is adopted by states that don't have their own OSHA programs currently in effect (Lopez, 2012). It is recommended that all fire stations follow the NFPA 1851 standard to keep the turnout gear in good condition to maintain its intended use.

NFPA 1851 section 7.2.1 recommends that protective clothing be evaluated after each use even if there is little or no evidence of contamination of potential hazardous materials and chemicals (NFPA, p. 20, 2014). The standard provides recommendations and steps for routine cleaning. They are as follows:

1. The washing machine should not be overloaded.
2. Areas that are heavily soiled or spotted should be pretreated.
3. All closures should be fastened including pocket closures, hooks and loops, snaps, zippers, and hooks.
4. Water temperatures should not exceed 105 degrees Fahrenheit.
5. A mild detergent with a pH range between 6.0 pH and 10.5 pH indicated on the product MSDS or original product should be used.
6. Washing machines with the capability of drum RPM adjustment shall be adjusted so the g-force does not exceed 100 g for all elements.
7. Follow the machine manufacturer's instructions for proper setting or program selection for the specific element being washed.
8. The element shall be inspected and rewashed if necessary.
9. Since the washing machine is used to wash items other than protective clothing ensemble elements, it should be washed out by running the machine without a laundry load through a complete cycle with detergent and filled to the maximum water level with a temperature of between 120 and 125 degrees Fahrenheit. (National Fire Protection Association, p. 20, 2014).

These cleanings and repairs can be made to the outer shell and the thermal liner of the turnout gear, but it is not recommended for the moisture barrier. The levels of contamination also vary; they can be different depending on the extent of the exposure to hazards. The Fire Industry Equipment Research Organization developed a set of guidelines in 1994 called "PPE Care and Use Guidelines", where it was recommended that the protective ensemble be retired from further use if the cost to repair the garment exceeded fifty percent of the original cost (Fire Industry Equipment Research Organization, 1994). The original manufacturer, or an individual who has had extensive training on how to recognize damage on a protective garment, must perform all repairs (National Fire Protection Association, 2013). Having these repairs performed by the manufacturer or by a trained individual can become very costly for fire stations, resulting in many fire departments overlooking the proper procedures of cleaning and maintaining the turnout gear.

Care and Maintenance of Firefighter Turnout Gear

The firefighter must become familiar with their turnout gear to ensure they maintain a sense of awareness when changes begin to occur that may affect the performance such as discoloration, rips, extreme soiling, etc. NFPA 1851, 2014 edition, requires firefighter turnout gear to be inspected after each use. Further, the gear should go through an advanced visual inspection every twelve months (NFPA, 2014). When a firefighter responds to a structural fire, it is important the proper procedures are followed in order to remove these hazardous substances (Sesko, 1991). Both cleaning and decontamination of protective clothing is required on a regular basis. It is important, during the cleaning process, that all three layers are recognized and thoroughly tended to (Jorgensen, 2002). Each layer has specific protective functions and is affected by contamination and cleaning differently.

Three types of cleaning defined by NFPA 1851 are routine, advanced, and specialized (NFPA, 2014). Routine cleaning can be defined as cleaning that is performed after any fire ground use where soiling can occur (NFPA, 2014). Routine cleaning involves brushing debris off from the turnout gear, rinsing with water by hand in a utility sink, and applying spot cleaner on the necessary areas (NFPA, 2014). Advanced cleaning should be done every twelve months or after time a set of turnout gear is soiled or used (NFPA, 2014). During advanced cleaning, the turnout gear should be washed in a washing machine with the exception of proximity shells and should follow proper procedures required by NFPA 1851. In situations where clothing is exposed to and contaminated by hazardous materials, the turnout gear should go through a specialized cleaning process. Specialized cleaning is often completed by a contract facility or professional (Stull, 2006).

In 2014, the Fire Protection Research Foundation completed a survey to determine the laundering practices within fire departments. They evaluated how firefighters maintain and care for their protective clothing and equipment (Stull, 2014).

The survey included the following questions:

1. How often are firefighters and fire departments cleaning their gear?
2. Who or which organizations are performing care and maintenance services?
3. Is contamination a concern among firefighters?
4. What is the average shelf-time (time spent in storage) of the gear?
5. Are firefighters using gear manufactured more than 10 years ago?
6. What happens to the gear once it is retired? (Fire Protection Research Foundation, pg. 169-185, 2014)

The survey was an open forum and categorized the respondents as individuals, staff personnel within the department who are responsible for cleaning, or as line firefighters with responsibilities to maintain the care of the turnout gear (Stull, 2014). The majority of the firefighters surveyed were full time (Stull, 2014). It was found that 75% of the fire departments have policies, procedures or suggestions in place for the care and maintenance of the turnout gear (Stull, 2014). Less than 50% of the departments and/or organizations follow NFPA 1851, although the majority of the policies suggested by NFPA 1851 are mandatory (Stull, 2014).

One-third of the departments have two or more sets of gear including coats, pants, hoods, and gloves (Stull, 2014). The departments are less likely to have extra helmets or footwear on hand (Stull, 2014). The majority of firefighters inspect their own gear after each fire or when it appears to be dirty (Stull, 2014). Individual firefighters are often responsible for the cleaning and care of their gear. However, many use a professional cleaning service to launder and repair their turnout coats and pants (Stull, 2014). The majority of the cleaning takes place in the individual fire stations. Those who did utilize professional cleaning services were not sure whether the facilities were verified to follow the NFPA 1851 standard (Stull, 2014).

At some fire departments, the firefighters themselves are responsible for the laundering of their turnout gear. Therefore many fire stations still do not have the equipment to provide proper laundering, care, and maintenance for protective ensembles. Also, some firefighters choose not to clean their turnout gear at all because it is a symbol of their bravery (Sesko, 1991).

Laundering of firefighter turnout gear is a requirement, especially when following the guidelines given by the manufacturers and NFPA. While it removes many of the contaminants that cause health hazards, it can also break down the garment materials and reduce their performance properties. It is important that proper procedures, during washing and drying, are followed and monitored to reduce the degradation of the garments. The drying process is a slow process and the recommended machine drying settings can potentially ruin the properties of the turnout gear. The turnout gear should be hung to air dry inside and out of light and direct sunlight to minimize the breakdown of the textile properties (Stull, 2006). The base composite materials may be damaged and/or soiled after each structural fire and require laundering. The laundering process sometimes involves a rigorous cycle that can damage the garment and further diminish the fibers (Stull, 2006).

The Firefighter Cancer Support Network, along with many other organizations, have compiled a list of suggestions to reduce the exposures that are relevant to the protective clothing use as well as hygiene practices (Firefighter Cancer Support Network, 2014). Some of the recommendations from these organizations are as follows:

1. Wear SCBA through all stages of the fire, including overhaul.
2. Remove as much of the bulk contamination as possible while still at the fire scene by performing gross contamination.
3. Wipe soot from your head, neck, jaw, throat, under arms and hands using wet wipes immediately after the fire.
4. Change and wash station wear, work wear, and other clothing right after returning to the station or leaving the fire ground.
5. Shower after the fire.
6. Ensure that all gear is thoroughly cleaned right after the fire.
7. Do not transport or take contaminated clothing home or store in a vehicle.
8. Keep all gear out of living and sleeping areas. (Firefighter Cancer Network, 2014)

In addition to these recommendations, the firefighter should wear their gear properly at all times to reduce the risks that are associated with the hazardous materials identified on the turnout gear (NFPA, 2014)

Manufacturer's Recommendations. User manuals are distributed with the purchase of new turnout gear for the user to effectively follow recommended maintenance procedures and effective laundering techniques along with general information about how to use the garment. Manufacturers' manuals go into lengthy detail of how the soiled turnout gear should be handled.

Lion Apparel Incorporated's user manual recommends the user have the turnout gear cleaned at least annually, or as soon as the gear has come into contact with contamination, exposure to smoke, bodily fluids or hazardous substances (Lion Apparel, 2014). The protective turnout garment should never be cleaned at home or in a Laundromat due to possible cross-contaminations. The manufacturer discourages the user from having the protective garment dry cleaned due to the loss of its protective and thermal functions, damaging the garment. It is recommended that layers of the turnout gear be washed separately to avoid redisposition of soils and contaminants. Garments are also to be checked regularly for possible repairs that need to be made to ensure the proper functional ability of the protective garment. Manufacturers provide these special instructions to guarantee the garment is being properly used and maintained.

Globe, Incorporated, another manufacturer of firefighter turnout gear attaches a label on every garment that provides very basic information for laundering (http://www.globeturnoutgear.com/turnout-gear/user-info/basic-care-cleaning, 2014). However, they do offer more comprehensive instructions for cleaning a set of turnout gear. Globe suggests that if the liners are detachable, that they should be removed from the shell and laundered separately to prevent any contaminants from being transferred to other layers of the garment during the laundering process (http://www.globeturnoutgear.com/turnout-gear/user-info/basic-care-cleaning. 2014). Globe recommends using a front-loading washing machine that does not have an agitator, and has been designed specifically for cleaning firefighter turnout gear (Globe, 2014). Care and cleaning facilities have a recommended g-force setting on the extractor which is the spin cycle and is important during the laundering process in order to remove the soils from the firefighter turnout gear. They suggest that 85 g's work best but no more than 100 g's (Globe, 2014).

In-House Cleaning. Decontamination is difficult, but necessary, to prevent cross-contamination among other garments or surfaces and to reduce the level of dermal absorption. In-house cleaning is not as efficient as a professional laundering service. Household detergents, mild and heavy duty, are often used and studies have shown that these often do not remove the most difficult contaminants from the turnout gear (TRI/Environmental, Inc., pg. 17, 1994). The contaminants that are left behind from the in-house laundering leave residue in the washer, often referred to as sludge, and can cross contaminate other pieces of gear along with everyday garments. Washing ensembles that are contaminated with high concentrations of flammables, resins, and/or blood borne pathogens is best left to experts (Zender, 2008). Small fire departments in the United States, which are usually low on funding, don't always practice the laundering procedures suggested by the NFPA 1851 (Stull, 2006). At fire departments that may not have access to funding, the firefighters often take responsibility for laundering their garments at their own discretion. For fire departments with limited funding, firefighters should rinse the garment upon arrival at the fire station. By rinsing the garment, it can reduce the buildup of light soot, dirt, and hydrocarbons that garments can accumulate during daily firefighting conditions (Zender, 2008). If the recommended laundering procedures published in NFPA 1851 are ignored, this creates issues that affect the protective clothing's textile properties. Laundering practices that aren't followed by the end user can lead to cross contamination among everyday apparel. By mishandling the gear, this leads to a decrease in the performance properties of the turnout and possible burns and increased dermal exposure (Stull, 2006). Parameters such as the wash cycle, detergent, water temperature, and drying temperature are suggested by NFPA 1851 to ensure the gear is being handled correctly and to lower the risk for diminished performance properties of the gear (NFPA, p. 19, 2014). NFPA 1851 recommends the turnout gear be cleaned in an NFPA compliant industrial washer with a water extraction speed of less than 100 g-force and a water temperature of less than 105˚F (Zender, 2008). By washing the garments with a controlled water temperature, it avoids the ruining of the liner and moisture barrier. It is important to rinse the garment thoroughly so that no soap residue remains on the garment; soap residue has a dangerously low flash point, suggesting that you shouldn't wash with more than the recommended amount of detergent (Zender, 2008). A proper pH level must also be maintained and monitored in the detergents used to clean the garment (Zender, 2008). The proper pH will clean, but not damage the garment. The standard suggest that you allow the garment to air dry or dry in a mechanical dryer less than 105˚F to prevent damage to the turnout gear (Zender, 2008).

Professional Cleaning Services. There are multiple organizations that specialize in the cleaning and decontaminating firefighter turnout gear. Professional Cleaning Services often use pretreatments, spot removers, oxygenated bleach, degreasers, and industrial cleaners. One of the cleaning services used by the Philadelphia Fire Department is 911 Safety Equipment. The owners of 911 Safety Equipment state "they only use cleaners which are specifically developed for high performance textiles and that the cleaners keep wash soils from redepositing onto fabrics." The cleaning products used by the professional laundering services are generally anionic formulas that are designed to remove the hydrocarbons from the turnout gear (Dexter Laundry, 2013). The formula treats the surface of the turnout gear to prevent soil from re-depositing onto the garment before the garment can be rinsed. Many professional cleaning services follow NFPA recommended standards when cleaning the turnout gear by maintaining a controlled environment and regulating the temperature for water used in wash cycles as well as the temperature for dry cycles (Dexter Laundry, 2013).

The firefighting turnout gear should first undergo cleaning and then are inspected in accordance with NFPA standards. The cleaning service can do a routine inspection, advanced inspection and/or a specialized inspection after laundering. These inspections are completed to assess the physical damage, missing items, and properties of the garment to ensure it is within compliance of NFPA guidelines.

Summary

Firefighters' lives are at risk on a daily basis, whether it is fighting a structural fire or failing to repair or clean their turnout gear in the most efficient way. Few studies have examined the cleaning procedures of protective turnout garments and looked at the potential threats of failing to do so. Manufacturers continue to change the designs and performance properties of protective clothing because they are more aware of the health risks associated with the tasks of firefighter. However, more research is needed in this area to ensure the upmost protection to each individual.

Recommended laundering practices are included in the user manuals and provided by NFPA but previous research has shown that these practices may not remove all of the contaminants and soils. This literature review suggests that the identification of soils on the Philadelphia Fire Department turnout gear will allow them to adopt a laundering process to remove the soiling without harming the protective properties of the turnout garment.

Chapter Three

Methodology

The purpose of this research was to identify the composition of soils on firefighter turnout gear from the Philadelphia Fire Department and to determine which soils contain hazardous materials. By first identifying the soils on the turnout gear, the soils will be further assessed for the potential health risks of hazardous materials present. In this study, soiled firefighter turnout gear was visually evaluated and specimens were removed from heavy soiled areas for laboratory analysis in order to identify the composition of the soils. This research will help identify the hazardous materials on the submitted Philadelphia Fire Department's firefighter turnout gear and determine if there is a health risk related to the soils. This chapter will summarize the methods used in the pilot study to analyze the specimens and identify the composition of soils on firefighter turnout gear. This chapter will also present the methods used in Phase I and Phase II of the study.

Research Design

A quasi-experimental research design was used in the pilot study to determine the most efficient method to analyze the soils on the Philadelphia Fire Department firefighter turnout gear. The same research design was used throughout the study for Phase I and Phase II of research. Samples of turnout gear were not randomly selected as they were a convenience sample provided by the Philadelphia Fire Department. Quantative data was collected and evaluated to determine the composition of the soils.

Pilot Study

The purpose of the pilot study was to determine the most efficient method for analyzing the specimens from firefighter turnout gear and to identify the composition of soils on the gear. A study completed by the U.S. Department of Health and Human Science Services that examined firefighter exposure to potential carcinogens found that the neck area is one of the most likely regions to become contaminated ("U.S. Department of Health and Human Science Services", 2014). The hood's structure and placement in direct contact with the skin allows an increased risk for the dermal absorption of contaminants.

Figure 3.1. Illustration of Nomex® Hood

Ten Nomex® hoods were obtained from the Philadelphia Fire Department; one new hood was used as a control, and the remaining nine were evaluated to identify the composition of soils. Specimens were removed from the hood samples and analyzed to identify the composition of soils and the presence of hazardous materials in or on the fire resistant fabric. Previous (unrelated) investigations found that soils and the presence of hazardous materials in or on flame resistant fabric can affect the flame resistant properties. Due to the nature of the fabric properties, hoods will stretch and wear out and because of the low cost of replacement, they typically are not laundered. As a result of the low cost, the hoods are often used only a few times and thrown away once they have been soiled in exchange for a new hood. Since the hoods are often worn only a few times before disposal and have not been subjected to laundering, the soiled hoods are considered to be a worst-case scenario of soiling.

The ten hoods were assigned a number to identify the results after collecting the data. The hoods were sent to DuPont in Richmond, Virginia for evaluation. A 500 mg sample was removed from each hood and placed in a 20 mL vial with nitric and hydrofluoric acid, then sealed with a crimp top cap. Each vial was heated in an automatic static headspace sampler at 110 degrees Celsius for 45 minutes. After the heating, an aliquot of the extract was injected into a gas chromatograph connected to a mass spectrometer also referred to as a GCMS. The gas chromatograph separated the chemicals and transferred the solution to the mass spectrometer which identified the composition. In the mass spectrometer, a “mass spectrum” is produced for each chemical peak by breaking it into smaller ions and measuring the charge, size, and number of ions produced. The identity of the soil composition was determined from its’ mass spectrum. The remaining solution from each vial was diluted with 100 milliliters of water before it was injected into an inductively coupled plasma mass spectrometry (ICP-MS) to identify trace metals. These same analytical procedures were used in Phase I of the study.

Phase I

Three sets of soiled firefighter turnout gear were received from the Philadelphia Fire Department for a total of six pieces; three turnout gear coats and three turnout gear pants. The gear received from the Philadelphia Fire Department did not have any documented history regarding repairs and/or launderings. Each set of gear was carefully handled, photographed and visually inspected according to NFPA 1851, Standard on Selection, Care and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting, 2014 Edition to document any holes, tears, and the overall soiling of the garment. Visual soiling was apparent on all three sets of turnout gear. For identification purposes, each set of gear was assigned a letter. Based on the overall soiling of the turnout gear, one set of gear was visually determined to have the highest amount of soiling. Compounds were selected based on current and prior research; an appropriate sampling process was also selected to identify any detection levels of the compounds. In total, five compounds were selected to be evaluated in Phase I. The following four compounds were selected based on the Kingsland study (2002): Octicizer® (2-ethylhexyl diphenyl phosphate), bis (Ethylhexyl) phthalate, Di-n-Octyl-phthalate, and Octacosane. A fifth compound, fluoranthrene, a polyaromatic hydrocarbon (PAH), also known as a burn product, was selected based on current research that suggest it may be a concern (FOX Biomonitoring, 2014). These contaminants were selected because they are associated with a family of compounds identified to have short and long term health effects.

Figure 3.2. Photographs of Soiled Turnout Gear Chosen for Analysis

Preparation of Specimens. For the purpose of analysis, areas of the turnout gear where the skin has been shown to have high dermal absorption were identified as areas to remove specimens for analysis. These areas were selected based on the Maibach 1971 study and included the neck/collar area, armpit, wrist area, and crotch area. Triplicate 2” x 2” samples were cut from each designated area from both the outer shell and the inner thermal liner, resulting in 24 specimens total (Figure 3.2). Specimens were cut from the right side of the sample in case any further testing needed to be conducted on the left side of the garment. A metal ruler, rinsed with isopropyl ethanol before and after each use, was used to measure the areas. The specimen areas were marked with a No. 2 lead pencil. Metal scissors used to cut specimens were rinsed with isopropyl ethanol before and after each use to prevent cross contamination. The specimens were placed in aluminum foil that was also rinsed with isopropyl ethanol prior to placement and storage. Specimens were labeled in accordance with the number they were assigned, and then shipped to DuPont (location) for analysis.

Treatments and Procedures. Although no cleaning history or documentation was available, it was assumed that the specimens cut from the soiled set of turnout gear were routinely cleaned. A portion of each specimen was weighed and then placed on a Dionex Automated Solvent Extractor (ASE) cell. An ASE instrument uses high temperatures and pressures to perform liquid extractions in a shorter amount of time compared to the traditional Soxhlet extractions. Each specimen was extracted with methylene chlorine. The extract was collected in a 60 ml vial. After the extraction was complete, the vial was placed in a Zymark Solvent Evaporator. The evaporator used a heated water bath and nitrogen flow to reduce the solvent to a smaller volume.

After the solvent was evaporated to a small volume, the vial was removed from the evaporator and allowed to cool to room temperature. The extract was then passed through a 0.2 µm syringe filter into a 10 ml vial. The weight of the extract was determined. The extract was then injected into a Gas chromatography–mass spectrometry (GCMS) instrument for analysis.

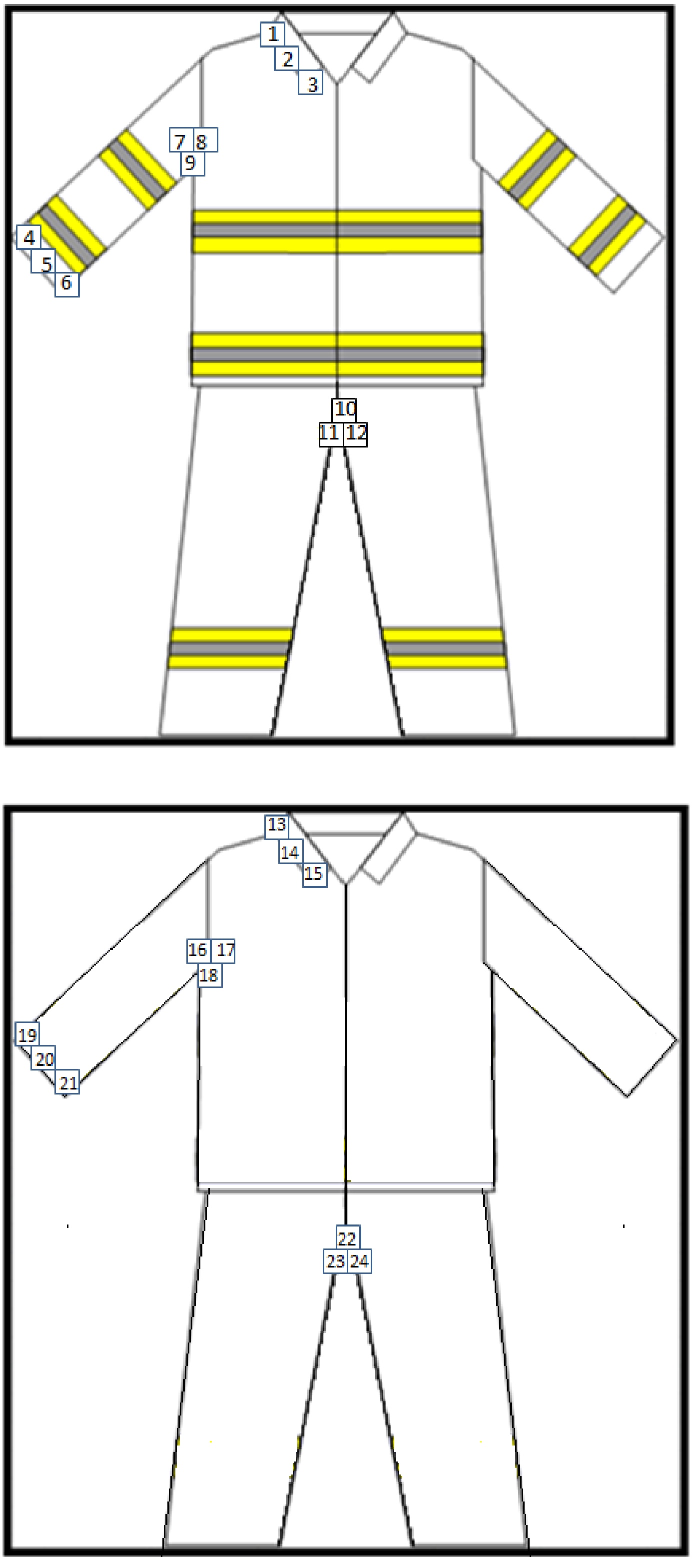

Figure 3.3. Phase I Specimen Locations (Top: Outer Shell, Bottom: Thermal Liner)

Phase II

Phase II was designed to further investigate the composition of soils present on the Philadelphia Fire Department turnout gear samples. Analytical procedures from the pilot study and Phase I were utilized. Twenty compounds were identified as potential hazards or toxins based on prior research and the pilot study in Phase I. A list of those compounds and justifications for selection are presented in Appendix B.

Sample. Soiled turnout gear was donated from the Philadelphia Fire Department. The gear donated was not cleaned prior to submittal. Seven turnout gear coats and seven turnout gear pants were selected with the criteria of having at least 3 to 5 years of use with documentation that each set of gear had been washed at least once annually. The gear was laundered in a Milnor 60lb extractor with the water temperature controlled not to exceed 105 degrees Fahrenheit. The gear went through two wash cycles and a total of five rinse cycles. A liquid detergent was used during the laundry process.

When the gear was received in the laboratory, each piece was photographed and visually examined to document holes, tears, and the amount of soiling. Extreme soiling was visually apparent on all samples. Each set of gear was assigned a letter, associated with the garment serial number, to be easily identified during data collection. The serial number aids in tracking the history associated with the garment itself. An identification number also reflects the location from which the sample was removed.

For purposes of analysis, areas of the turnout gear where the skin has been shown to have high dermal absorption were identified as areas to remove specimens for analysis. These areas were selected based on the Maibach 1971 study and included the neck/collar area, armpit, wrist area, and crotch area.

Table 3.1

Compound List & Justifications

Substance	Class	Justification
DEHP	Plasticizer	Kingsland Study
DOP	Plasticizer	Kingsland Study
BzBP Benzyl butyl phthalate	Plasticizer	FOX Biomonitoring (FOX)
Octicizer®	phosphate flame retardant	Kingsland Study
Octacosane	Hydrocarbon	Kingsland Study
Fluoranthrene	Polyaromatic Hydrocarbon (PAH)	Phase I
Antracene	PAH	NIOSH Study
Benzo(a) Pyrene	PAH	NIOSH Study
Chrysene	PAH	NIOSH Study
Phenanthrene	PAH	NIOSH Study
Pyrene	PAH	NIOSH Study and Kingsland Study
BDE 28 (2,4,4 tribromodiphenyl ether)	Polybrominate diphenyl ethers (PBDE)	FOX Biomonitoring
BDE 47 (2,2,4,4,6 Tetrabromodiphenyl ether)	PBDE	FOX Biomonitoring
BDE 99 (2,2,4,4,5 Pentabromodiphenyl ether)	PBDE	FOX Biomonitoring
BDE 100 (2,2,4,4,6 Pentabromodiphenyl ether)	PBDE	FOX Biomonitoring

Table 3.1

Compound List & Justifications (continued)

Substance	Class	Justification
BDE 153 (2,2,4,4,5,5 Hexabromophenyl ether)	PBDE	FOX Biomonitoring
PCB 194	PCBs	FOX Biomonitoring
Dibromo Dibenzofuran	thermolysis products	Phase I
Naphthalene	PAH	IARC
Pentachlorophenol	PVC incomplete combustion product	IARC

(Kingsland, 2003; FOX Biomonitoring, 2013; NIOSH, 2013; IARC, 2011)

Sample Preparation. Soiled turnout gear was stored in a controlled, dark environment with a temperature at 70° degrees Fahrenheit ± 2 degrees and relative humidity at 65 degrees Fahrenheit ± 2 degrees until specimens were removed from the right side of the coat and pant. The left side of the coat and pant were stored for further analyzing. Prior to cutting specimens from the designated area, the coats and pants were visually evaluated in order to document the condition of the labels, overall soiling, physical damage, and functionality of the turnout gear. The results of the visual inspection can be found in Appendix C. The specimens cut from the wristlet were 2” x 2” squares. Samples removed from the collar area, armpit area, and crotch area were 4” x 4” squares. A metal ruler rinsed with isopropyl ethanol was used to measure each specimen and the areas were marked with a No. 2 lead pencil. Specimens were cut using metal scissors rinsed with isopropyl ethanol before and after each use to prevent cross contamination. All specimens were placed in aluminum foil that was also rinsed with isopropyl ethanol prior to storage of the specimens. Specimens were labeled according to an assigned number based on location on the gear. All specimens were shipped to Lancaster Labs Eurofins in Lancaster, Pennsylvania for analysis.

Treatments and Procedures. After review of methylene chloride extraction results found in Phase I, it was thought that using EPA standardized methods for soil and solid waste which have been validated for hundreds of compounds might be more reliable in Phase II. Several analytical laboratories were queried for recommendations. Lancaster Laboratories, now part of Eurofins Laboratory in Lancaster, Pennsylvania, was selected based on their experience in using the EPA SW-846 methods.

The Eurofins Laboratory was consulted regarding sample size to ensure adequate detection limits as DuPont chemists reported that extraction results based on 2" x 2" samples were close to detection limit. The Eurofins Laboratory indicated the largest sample size they could extract was 4" x 4". The 4" x 4" square inch samples were extracted via method EPA SW-846 3546 which involves microwave assisted extraction of the sample in a 1:1 mixture of methylene chloride and acetone. The EPA SW-846 3546 method is a procedure for extracting water insoluble or slightly water soluble organic compounds from soils or waste. The procedure uses microwave energy to produce elevated temperature and pressure conditions, for example 110-115° C and 50-175 pounds per square inch (psi). The specimen is placed in a closed vessel with organic solvents to achieve analytical recoveries. This method is applicable to semi-volatile organic compounds, pesticides, substituted phenols, PCB's and PCDDs/PCDFs which can be analyzed by a variety of chromatographic procedures. The GC/MS analysis followed EPA SW-846 8270. The EPA SW-846 8270 method is a procedure used to determine the concentration of semivolatile organic compounds in extracts prepared from many types of soils and solid waste. Appropriate preparation techniques are outlined in detail in Method 8270D-1 ("EPA", 2014). In addition to the sample preparation methods, a solid-phase extraction procedure is applied to extract semi-volatiles.

Specimens were removed from samples of turnout gear and analyzed by Eurofins Laboratory in Lancaster, Pennsylvania. The specimens were evaluated for identification of soil type for the twenty compounds selected based on prior studies. The specimens that were cut from the soiled sets of turnout gear have documentation from the professional laundering company, 911 Safety Equipment that cleans the Philadelphia Fire Departments turnout gear, that the gear meets the criteria to have been routinely cleaned at least once per year.

At Eurofins Laboratory, a portion of each specimen was weighed and then placed on a Dionex Automated Solvent Extractor (ASE) cell. An ASE instrument uses high temperatures and pressures to perform liquid extractions in a much shorter amount of time compared to the traditional Soxhlet extractions. Each specimen was extracted with methylene chlorine. The extract was collected in a 60 ml vial. After the extraction was complete, the vial was placed in a Zymark Solvent Evaporator. The evaporator uses a heated water bath and nitrogen flow to reduce the solvent to a small volume. After the solvent was evaporated to a small volume, the vial was removed from the evaporator and allowed to cool to room temperature. The extract was then passed through a 0.2 µm syringe filter into a 10 ml vial. The weight of the extract was determined. The extract was then injected into a gas chromatography–mass spectrometry (GCMS) instrument for analysis.

Data Analysis

The data collected for the Pilot Study, Phase I, and Phase II was organized within Microsoft Excel data spreadsheets. Each soil identified within each phase was analyzed and a risk assessment was performed using a calculation suggested by the EPA. The calculation allowed the researcher to determine if the soils found on the firefighter turnout gear and hoods were detected in quantities that would be considered a risk to the firefighter. Graphs and tables which can be found in Chapter 4 were used to communicate test results.

Chapter Four

Results and Discussion

The purpose of this research was to identify the composition of soils on firefighter turnout gear from the Philadelphia Fire Department and to determine which soils contain hazardous materials. Soils were identified on specimens removed from Philadelphia Fire Department turnout gear and evaluated to determine the potential health risk that firefighters are potentially faced with.

Pilot Study

Initially, a pilot study was conducted to determine the most efficient method to analyze specimens removed from the turnout gear and identify the composition of soils on the gear. Ten Nomex® hoods were obtained from the Philadelphia Fire Department. A new hood was retained as the control and the remaining nine were sent to DuPont Experimental Station in Wilmington, Delaware to be tested. In the laboratory, specimens were removed from the hoods and analyzed to identify the composition of soils. The specimens were placed in a sealed vial and heated at 110°C for 45 minutes and then the headspace was analyzed by gas chromatography for volatile compounds. The analysis identified several compounds in the soils from the hoods. Table 4.1 lists the compounds identified during this analysis of the used hoods and notates the soils that were identified on the control hood. Quantification of the compounds detected was not performed but the control hood had smaller peaks for the same compounds.

Table 4.1

Compounds Identified on Hoods

Soils Identified	Detected in the Control Hood
Acetaldehyde	√
Acetone	√
carbon disulfide	√
2-methyl propanal	
methacrolein	
acetic acid	√
3-methyl furan	
3-methyl butanel	
2-methyl butanel	

Table 4.1

Compounds Identified on Hoods (continued)

Soils Identified	Detected in the Control Hood
pentanal	
Hexanal	√
Siloxane	√
Heptanal	√
oxepine, 2, 7-dimethyl	
Benzaldehyde	
2-pentyl furan	
Octanal	√
Nonanal	√
Decanal	√
phenolic antioxidant derivative	
Pentadecane	

Specimens removed from the hoods were also analyzed for the presence of trace metals using an Inductively Coupled Plasma Mass Spectrometry (ICP-MS). This type of mass spectrometry is capable of detecting metals and several non-metals at concentrations as low as one part per 10^{12} (part per trillion). Table 4.2 summarizes the results of the trace metal analysis. Thirty four trace metals were identified at some level on the hoods.

Table 4.2

Results of the ICP-MS Analysis of Trace Metals

ICP- MS Trace Metal Analysis (µg/g)					
Trace Metals	Control Hood	Used Hoods	Trace Metals	Control Hood	Used Hoods
Berylliu (Be)	<0.5	<0.05-0.06	Selenium (Se)	<0.05	<0.05-0.52
Sodium (Na)	744	2540-24800	Rubidium (Rb)	0.12	1.9-7.58
Magneisum (Mg)	16.6	293-2500	Strontium (Sr)	0.6	3.56-47.7
Aluminum (Al)	36.9	357-3230	Zirconium (Zr)	0.63	4-67.4
Potassium (K)	103	744-5680	Niobium (Nb)	0.13	0.08-0.88

Table 4.2

Results of the ICP-MS Analysis of Trace Metals (continued)

ICP- MS Trace Metal Analysis (µg/g)					
Trace Metals	Control Hood	Used Hoods	Trace Metals	Control Hood	Used Hoods
Calcium (Ca)	69	613-12200	Molybdeum (Mo)	0.15	0.47-1.66
Titanium (Ti)	<0.05	83-1680	Silver (Ag)	<0.05	0.11-1.29
Vandium (V)	0.02	0.58-4.90	Codmium (Cd)	<0.05	0.39-4.12
Chromium (Cr)	1.18	8.93-76.9	Tin (Sn)	0.2	2.59-21.9
Manganese (Mn)	0.48	4.76-41.9	Antimony (Sb)	3.35	12.3-52.2
Iron (Fe)	44.9	208-1620	Tellurium (Te)	<0.1	<0.1
Cobalt (Co)	<0.05	0.26-1.77	Cesium (Cs)	0.05	0.12-0.41
Nickel (Ni)	1.23	4.46-31.0	Barium (Ba)	8.58	33.8-297
Copper (Cu)	2.51	13.9-89.2	Lanthanum (La)	<0.05	0.31-2.43
Zinc (Zn)	30.8	219-1110	Cerium (Ce)	<0.05	0.63-4.93
Arsenic (As)	0.09	0.58-20.7	Tungsten (W)	<0.05	0.11-1.02
Mercury (Hg)	<0.05	<0.05-0.45	Lead (Pb)	0.59	31.7-922

A risk assessment was conducted on the trace metals by estimating the potential for dermal exposure to the trace metals found in the hoods. The EPA dermal absorbed method was used to calculate a conservative approach that the substances identified would be dermally absorbed (EPA, 2004). The dermal dose times the concentration was divided by the basis weight of the specimens. The focus was on soluble species of the trace metals rather than oxides. The calculation was as follows:

Dermal Absorbed Dose (ug/day) = Cw x Kp x SA x t

Equation 1 where:

Dermal Absorbed Dose (DAD) = estimated dermal dose for exposure scenario (ug/day)

Cw = the concentration of metal in water (ug/cm^3)

Kp = the skin permeation coefficient (cm/hr)

SA = the skin surface area in contact (cm^2)

t = exposure time (hr)

Cw was determined by taking the acid digestion results in ppm x basis weight of fabric, assumed to be 20 mg/cm^2. A specimen of fabric was extracted and the surface extraction was converted to concentration. It was assumed that the maximum volume required to cover 1cm^2 was10 ul. This was based on invitro dermal testing guidance that indicates liquid coating of skin maximizes at 10 ul/cm^2. Kp was based on experimental measurement or EPA defaults (EPA,2004). The skin surface area used for the hoods was 1155 cm^2 (3/4 adult male head, 95th percentile) (EPA Exposure Factors Handbook, 2011 Chapter 7). The time of exposure for this scenario was two hours. Risk Assessment could only be performed for the metals with identified health benchmarks such as EPA oral reference dose (EPA RfD) from the EPA Integrated Risk Information System (IRIS), allowable daily intake (ADI) recommendations or tolerable daily intake (TDI) values from the U.S. Food and Drug Adminstration (FDA) or the equivalent European Commission or EFSA. The substance specific information used in the risk assessment is listed in Table 4.3 when no reference Kp was available 0.001 was used as an inorganic default as recommended in EPA guidance (EPA 2004). The results of the calculated risk assessment are presented in Table 4.4 and include exposure divided by health benchmark to estimate Risk Characterization Ratio (RCR).

Table 4.3

Values used for the Metal Risk Assessment

Metal	Kp (cm/hr)	Source for Kp	Health benchmark (ug/day)	Source for Heath benchmark
Be	0.001	EPA 2004, Exhibit B-4	140	EPA RfD
Na	0.0012	EPA 2004, Exhibit A-6	2.3E+06	FDA recommends no more than 2300 mg/day
Mg	0.001		2.5E+05	EFSA TDI
Al	0.001		70000	CDC ASTDR Minimum Risk Level (1 mg/kg/day)
K	0.002	EPA 2004, Exhibit A-6	4.7E+06	Food and Nutrition Board Institute of Medicine of the National Academies TDI, 2004
Ca	0.001		2.5E+06	
Ti	0.001		No limit	
V	0.001	EPA 2004, Exhibit B-4	70	EPA TDI

Table 4.3

Values used for the Metal Risk Assessment (continued)

Metal	Kp (cm/hr)	Source for Kp	Health benchmark (ug/day)	Source for Heath benchmark
Cr	0.0027	EPA 2004, Exhibit A-6	210	EPA RfD for Cr (VI)
Mn	0.001	EPA 2004, Exhibit B-4	9800	EPA RfD
Fe	0.001		50000	EFSA TDI
Co	0.001		1600	Norweigian Scientific Committee for Food Safety, TDI, 2007
Ni	0.00027	EPA 2004, Exhibit A-6	770	World Health Organization TDI for drinking water, 2005
Cu	0.001	EPA 2004, Exhibit B-4	2000	EU TDI
Zn	0.0006	EPA 2004, Exhibit B-4	21000	EPA RfD
As	0.001	EPA 2004, Exhibit B-4	0.4	EPA cancer oral slope based on 1/10000 cancer risk drinking 2 L/day of water
Se	0.001	EPA 2004, Exhibit B-4	350	EPA RfD
Rb	0.001		No information	
Sr	0.001		8000	EPA drinking water guidelines assume drink 2L/day
Zr	0.001		No information	
Nb	0.001		No information	
Mo	0.001		350	EPA RfD
Ag	0.0006	EPA 2004, Exhibit B-4	350	EPA RfD
Cd	0.0011	EPA 2004, Exhibit A-6	35	EPA RfD
Sn	0.001		21	EPA RfD for tributyl tin

Table 4.3

Values used for the Metal Risk Assessment (continued)

Metal	Kp (cm/hr)	Source for Kp	Health benchmark (ug/day)	Source for Heath benchmark
Sb	0.001	EPA 2004, Exhibit B-4	28	EPA RfD
Te	0.001		350	Based on 175 ug/L Human Reference Level for drinking water EPA
Cs	0.001		No information	
Ba	0.001		14000	EPA RfD
La	0.001		No information	
Ce	0.001		18	EPA RfC assume inhale 20 m^3/day
W	0.001		No information	
Hg	0.00093	EPA 2004, Exhibit A-6	6	EPA RfC assume inhale 20 m^3/day
Pb	0.00013	EPA 2004, Exhibit A-6	30	Based on EPA drinking water limit assume drink 2L/day

Example Calculation for Arsenic

$$\text{Dermal Absorbed Dose (DAD)} = Cw \times Kp \times SA \times t$$

$$Cw = \frac{\text{average extraction result (ug/g)} \times \text{basis weight}(g/cm^2) \times 1000 ul/ml}{10\ ul/cm^2 \text{ (max liquid loading on skin)}}$$

$$Cw = 4.1\ ug/g \times 0.02\ g/cm^2 \times 1000\ ul/ml = 8.2\ ug/cm^3$$

$$DAD = 8.2\ ug/cm^3 \times 0.001\ cm/hr \times 1155\ cm^2 \times 2\ hrs = 18.9\ ug/day$$

Table 4.4

Risk Assessment of Exposure to Trace Metals

Metal	Estimated Dermal Absorbed Dose (ug/day)	Health benchmark (ug/day)	Risk Characterization Ratio
Be	0.3	140	0.002
Na	44812	2.3E+06	0.02
Mg	7267	2.5E+05	0.03
Al	8251	70000	0.1
K	23174	4.7E+06	0.005
Ca	30464	2.5E+06	0.01
Ti	2786	No limit	NA
V	13.9	70	0.2
Cr	461	210	2.2
Mn	116	9800	0.01
Fe	4504	50000	0.09
Co	4.6	1600	0.003
Ni	22	770	0.03
Cu	292	2000	0.2
Zn	1635	21000	0.08
As	18.9	0.4	47
Se	0.9	350	0.003
Rb	18.9	No information	NA
Sr	140	8000	0.02
Zr	152	No information	NA
Nb	2.8	No information	NA
Mo	5.5	350	0.02
Ag	1.7	350	0.005
Cd	11	35	0.3
Sn	46	21	2.2
Sb	145	28	5.2

NA = not applicable

Table 4.4

Risk Assessment of Exposure to Trace Metals (continued)

Metal	Estimated Dermal Absorbed Dose (ug/day)	Health benchmark (ug/day)	Risk Characterization Ratio
Te	0.5	350	0.001
Cs	0.9	No information	NA
Ba	822	14000	0.06
La	7.4	No information	NA
Ce	13	18	0.7
W	1.8	No information	NA
Hg	0.9	6	0.1
Pb	170	30	5.7

NA = not applicable

An RCR less than 1 was not considered to be a health concern. RCRs above 1 require further evaluation. The health benchmarks were selected from the EPA Integrated Risk Information System (IRIS) (EPA, 2014). The oral reference dose (RfD) was the preferred choice except for arsenic (As) in which the carcinogenic health benchmark of 0.4 ug/day was used. If no health benchmark could be found, dietary daily allowable doses were used for the worst-case estimates.

Trace metals with an RCR>1 for the two-hour hood scenario were: Al, Cr, As, Sn, Sb, and Pb. Given that the extraction methods were aggressive these five metals were further reviewed. The health benchmarks selected aluminum (Al) and chromium (Cr) were identified as unreasonable. Al has a dietary daily allowable dose of 1.6mg to 13mg per day and no regulatory body has identified a level of concern for Al (EFSA, 2008). The Cr health benchmark is for Chromium (VI) which is not the common form found in the environment. The extraction method does not distinguish between the two forms [Cr (VI) and Cr (III)] and Cr (III) is not toxic. The health benchmark for tin (Sn) assumes the tin was in the form of tribuyltin oxide which again is unlikely since this substance has been mainly used as a marine antifouling agent for boats. This reduces the list of metals to arsenic for carcinogen risk. Arsenic is a compound that is present in the environment and people are exposed to it from food and drinking water. Saline extraction from the fabric should be considered for arsenic to see if it is readily available for dermal absorption. Biomonitoring of firefighters could also reveal if the blood levels of arsenic are higher than the United States' general population as this substance is routinely monitored in the CDC NHANES biomonitoring study. The California Fox Biomonitoring program found the arsenic levels in firefighters to be below the NHANES general population results indicating that for California firefighters it was not a significant concern. The procedures and methods to analyze the soils on the hoods were reviewed and taken into consideration in the next phase of the project.

Phase I

After reviewing the results of the pilot study, Phase I was conducted to evaluate the composition of soils on turnout gear from the Philadelphia Fire Department. One set of gear (coat and pant) was evaluated. A visual assessment of the gear identified the level of soiling as heavy. Based on an earlier study by Maibach, 1971 that identified areas of the body susceptible to high levels of dermal absorption (neck/collar area, armpit, wrist and crotch), twenty four specimens were removed from these areas on the turnout gear including the outer shell and thermal liner. The specimens were analyzed for the presence of five compounds: Octicizer® (2-ethylhexyl diphenyl phosphate), bis (ethylhexyl) phthalate (DEHP), Di-n-Octyl-phthalate, octacosane and fluoranthene. The compounds were selected from those evaluated by Kingsland (2003) and the results of the pilot study.

Table 4.5 summarizes the quantities of the five compounds in ug/g (ppm) from the twenty four specimens removed from the turnout gear sample. The quantity of each compound varied depending on the soil level of the turnout gear and the location of the specimen on the gear.

Table 4.5

Compounds Identified on Turnout Gear – Phase 1

Specimen Number	Coat/Pant	Area	Outer Shell	Thermal Liner	Compounds- Amount in ug/g (pmm)				
					DEHP	Di-n-Octyl-phthalate	Fluoranthene	Octicizer®	Octacosane
1	Coat	Collar	X		1.3	0	0.06	0	1.3
2	Coat	Collar	X		3.7	0	0.18	0	1.47
3	Coat	Collar	X		8.66	0	0.1	0	1.18
4	Coat	Armpit	X		2.17	0	0.09	0	3.2
5	Coat	Armpit	X		13.28	0	0.13	0	48.59
6	Coat	Armpit	X		7.35	0	0.38	0.78	13.82
7	Coat	Wrist	X		2.67	0	0.31	0	0.42
8	Coat	Wrist	X		5	0	0.45	1.25	0.98
9	Coat	Wrist	X		7.36	0	0.64	1.63	0.35
10	Pant	Crotch	X		11.31	0	6.3	21.43	0.97
11	Pant	Crotch	X		14.97	0	14.2	30.99	1.26
12	Pant	Crotch	X		4.73	0	3.51	16.42	0.85
13	Coat	Collar		x	1.66	0	0.14	0.2	0.26
14	Coat	Collar		x	0.07	0	0	0	0.9
15	Coat	Collar		x	1.75	0	0.21	0.14	0.33
16	Coat	Armpit		x	3.09	0	0.25	0.25	1.21
17	Coat	Armpit		x	4.23	0	0.46	0	2.08
18	Coat	Armpit		x	0.68	0	0.08	0.02	0.78

Table 4.5 (continued)

Compounds Identified on Turnout Gear – Phase 1

Specimen Number	Coat/Pant	Area	Outer Shell	Thermal Liner	Compounds- Amount in ug/g (pmm)				
					DEHP	Di-n-Octyl-phthalate	Fluoranthene	Octicizer®	Octacosane
19	Coat	Wrist		x	1.67	0	0.21	0	1.28
20	Coat	Wrist		x	3.36	0	0.32	0	2.5
21	Coat	Wrist		x	1.34	0	0.22	0	1.19
22	Pant	Crotch		x	3.82	0	2.39	2.05	0.96
23	Pant	Crotch		x	1.7	0	1.33	0.98	0.84
24	Pant	Crotch		x	1.01	0	0.97	0.71	0.2

In addition to reporting the amount of compound on each specimen (Table 4.5) the data as reported in Table 4.6 shows the average amount of each compound according to the location on the garment where the specimens were taken (collar, armpit, wrist, and crotch) for the outer shell or the thermal liner. The average was calculated and recorded in ug/g (ppm).

Table 4.6

Results Grouped to Show the Location of Specimens on the Turnout Gear

Results Grouped to Show the Location of Specimens in ug/g (ppm)							
Layer of Gear	Specimen #	Location of Specimen	DEHP	Di-n-Octyl-phthalate	Fluoranthene	Octicizer®	Octacosane
Outer Shell	1-3	Collar	4.55	0.00	0.11	0.00	1.32
	4-6	Armpit	7.60	0.00	0.20	0.26	21.87
	7-9	Wrist	5.01	0.00	0.47	0.96	0.58
	10-12	Crotch	10.34	0.00	8.00	22.95	1.03
Thermal Liner	13-15	Collar	1.16	0.00	0.12	0.11	0.50
	16-18	Armpit	2.67	0.00	0.26	0.09	1.36
	19-21	Wrist	2.12	0.00	0.25	0.00	1.66
	22-24	Crotch	2.18	0.00	1.56	1.25	0.67

As noted in Table 4.4 di-n-Octyl phthalate a plasticizer used to make plastics more flexible or soft to touch was not found on any of the twenty four specimens. However, DEHP, fluoranthene, Octicizer® and octacosane were found on some specimens taken from four areas of the gear. DEHP is the most common of the class of phthalates used as plasticizers and was detected in all twenty four specimens from the outer shell and the thermal liner. The highest level of DEHP (14.97 ug/g) was found on specimen #11 which was taken from the crotch area of the outer shell. Specimens removed from the armpit and crotch areas of the thermal liner showed increased levels of DEHP. DEHP is classified a Group 2B, possibly carcinogenic to humans by the IARC Monograph (Thomas, 2010). In 2011, the European Commission recommended that the use of DEHP cease because of the reproductive toxicity to humans (Mercola.com, 6/24, 2011).

Fluoranthene was extracted from twenty three of the twenty four specimens. The only specimen that did not contain fluoranthene was number 14, which was removed from the crotch area of the thermal liner. However, high levels of fluoranthene were found in the crotch area of the outer shell (pants) with an average of 8.00 ug/g. The highest amount of fluoranthene was found on specimen #11 (14.20 ug/g) taken from the crotch area (pant) of the outer shell. Fluoranthene was found on both the outer shell and the thermal liner in the armpit, collar, crotch and wrist areas. Fluoranthene is classified as a Group 3, not classifiable as to its carcinogenicity to humans in the IARC Monograph (2014).

Octicizer®, a trade name for Phosphoric Acid Diphenyl 2-ethylhexyl Ester. Octicizer® is a general purpose plasticizer that can form the highly toxic and flammable phosphine gas if exposed to strong reducing agents. Octicizer® was detected on thirteen of the twenty four specimens. Octicizer® was found in extremely high levels in the crotch area of the outer shell at 22.95 ug/g. Specimen #11 which was taken from the crotch area of the outer shell had the highest level of Octicizer® at 30.99 ug/g. Specimen #10 was also taken from the crotch area of the outer shell and 21.43 ug/g of Octicizer® was found on this specimen. For the thermal liner, the highest level of Octicizer® (2.05ug/g) was found in specimen #22 which was removed from the crotch area. The levels of Octicizer® found in the crotch area raises concern since it can be absorbed through the skin (toxnet.com, 2002).

Octacosane is insoluble in water and as a liquid can easily penetrate through fabrics and produce skin irritation. The effects of human exposure to octacosane in human subjects include irritation of the eyes, skin and respiratory tract along with headaches, dizziness, and fatigue (EPA, 2014). N-Octacosane is a C_{28} hydrocarbon and has little health hazard information available about this compound in particular. Further investigation indicates that it is in the class of paraffin waxes. Paraffin waxes are a mixture of straight chain hydrocarbons having carbon numbers predominantly greater than C20 and are not classified as dangerous and are generally recognized as safe (GRAS) for use in food in the United States and the European Union (EPA, p. 43, 2014).

Since no health effects have been identified this substance should be dropped from future studies.

Octacosane was detected on all twenty four specimens removed from the sample of turnout gear in Phase 1. High levels of octacosane were found in the armpit area of the outer shell at 48.59 ug/g (ppm). For the thermal liner, the highest level of octacosane was found in the armpit area at 2.08 ug/g which may indicate permeation through the fabric of the outer shell. For the outer shell the armpit area showed the highest level of octacosane at 21.87 ug/g. Specimens #5 and #11 had the highest detection levels of the twenty four specimens. Specimen #5 was removed from the armpit area of the outer shell and reported the highest levels of octacosane and bis (ethylhexyl)-phthalate. Since no health effects have been identified for octocosane it should be dropped from future studies.

The history of care and maintenance of the sample of turnout gear in Phase I was not available to the researcher. Therefore, it was decided that in order to gain a better understanding of the composition of soils on turnout gear that has been cared for and maintained according to NFPA 1851 standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting, a second phase of the study was conducted.

Phase II

The second phase was an expansion of Phase I with the purpose to identify the composition of soils found on firefighter turnout gear from the Philadelphia Fire Department. When selecting the samples to be evaluated for Phase II, documented wash history was mandatory illustrating that the selected samples had been laundered at least one time per year (Appendix C). Seven sets of soiled turnout gear were provided by the Philadelphia Fire Department. The gear had been in use at least three to five years and had been cleaned at least once per year. As in Phase I, specimens were removed from the areas of the gear known to have high levels of dermal absorption (Maibach, 1971). The wristlet area was added to the locations from which specimens were taken due to the known area of high absorption found by other researchers.

Analysis of the specimens included the five compounds in Phase I and sixteen additional compounds were evaluated. The compounds were as follows: Group 1 – Polyaromatic Hydrocarbons (PAH): anthracene, benzo(a) pyrene, chrysene, fluoranthene, naphthalene, phenanthrene and pyrene; Group 2 – Plasticizers: butylbenzylphthalate, dimethyl phthalate and di-n-octylphthalate, bis (2-ethylhexyl) phthalate: Group 3 – Polyvinyl Chloride (PVC): pentachlorophenol ; Group 4- Polybromominated Diphenyl Ethers or a thermolysis product from PBDE (PBDEs) – flame retardants: 1,8-dibromo dibenzofuran (DBDBF), 2,4,4'-tribromodiphenyl ether (PBDE-28), 2,2',4,4',5-pentabromodiphenyl ether (PBDE-99), 2,2',4,4',6-pentabromodiphenyl ether (PBDE-100), 2,2',4,4'tetrabromodiphenyl ether (BDE-47),and 2,2',4,4',5,5'hexabromodiphenyl ether (PBDE-153); Group 5-PO43: 2-ethylhexl diphenyl phosphate (Octicizer®) a phosphate flame retardant; Group 6 – polychlorinated biphenyl(PCB): 2,2',3,3',4,4',5,5'octachlorobiphenyl (PCB-194); and Group 7- Hydrocarbon: N-octacosane.

Table 4.7 presents the results by reporting the range (ug/kg) of each compound extracted from the fifty six specimens. The results are grouped according to the area of the gear that the specimens were removed. The quantity of each compound varied depending on the soil level of the turnout gear and the location of the specimen on the turnout gear. Of the twenty compounds evaluated in Phase II, two compounds, DBDBF and PCB 194 were reported at levels below the minimum detection level (<MDL).

Table 4.7

Phase II Compounds Identified in the Specimens from Turnout Gear

Compounds (CAS Number)		Outer Shell			Thermal Liner			Wristlet	
		Collar	Armpit	Crotch	Collar	Armpit	Crotch	In Contact	Outside
		ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg
PAH	anthracene (120-12-7)	<350-800	<590-2100	<480-1900	<200-450	<160-390	<240-440	<510-1100	<550-1600
	benzo (a) pyrene (50-32-8)	<350-1300	<590-7400	510-6000	<200-820	<160-650	<240-910	<510-3500	<550-5300
	chrysene (218-01-9)	<350-3500	580-23000	2300-11000	<200-1700	<1600-1500	150-900	650-7800	710-9200
	fluoranthene (206-44-0)	530-6200	860-9200	1300-16000	470-2300	260-1200	30-1600	650-8200	610-8000
	napthalene (91-20-3)	<370-<290	<590-<510	<720-450	<200-<150	<160-<140	<240-2300	<510-<370	<550-<410
	phenanthrene (85-01-8)	630-4300	960-6300	2100-8600	420-1900	230-1600	480-1800	570-3100	550-2900
	pyrene (129-00-0)	460-5500	690-7900	1100-15000	390-1800	<160-1000	<240-330	640-7100	<470-7900
Plasti-cizer	butylbenzylphthalate (85-68-7)	<3600-4900	<5800-7500	<4700-12000	2200-5100	<1600-<1300	<1200-2500	<3900-11000	4900-21000
	Dimethyl phthalate (131-11-3)	<3600-<2900	<5700-<5000	<7000-<27000	<2000-<14000	<1600-<1300	<2300-<600	<500-<440	<5400-<4000
	di-n-octylphthalate (117-84-0)	<3500-10000	8300-33000	<4700-36000	2500-11000	<1600-4100	<2300-2100	5900-11000	4900-17000

Table 4.7(continued)

Phase II Compounds Identified in the Specimens from Turnout Gear

Compounds (CAS Number)		Outer Shell			Thermal Liner			Wristlet	
		Collar	Armpit	Crotch	Collar	Armpit	Crotch	In Contact	Outside
		ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg
PVC*	Pentachlorophenol (87-86-5)	<3700-<2900	<5900-<5100	2100-8600	<2000-<180	<1600-<1400	<2400-<610	<5100-<3700	<5500-<4200
PBDE	DBDEF (10016-52-1)	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
	PBDE-28 (41318-75-6)	<MDL-3476	<MDL	<MDL	<MDL-639	<MDL	<MDL	<MDL	<MDL
	PBDE-100 (189084-64-8)	831-560096	1094-2494	<512-40533	220-36648	<MDL-513	<MDL-152	<245-3545	<246-5230
	PBDE-47 (40088-47-9)	3571-1503921	3922-10851	7990-1510	2120-125991	<119-2555	244-658	925-16120	831-22333
	PBDE-153 (68631-49-2)	<284-185025	<477-974	<MDL-858	<134-13541	<MDL-222	<MDL-70	<MDL-1200	<302-1483
P043**	Octicizer ® (1241-94-7)	2925-109150	2594-112618	6121-179864	1418-62442	569-18709	476-12116	13716-302403	11408-164514
PCB	PCB-194 (35694-08-7)	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Hydro-carbon	octacosane (630-02-4)	3640-57130	6691-12632	3640-25969	4347-33052	1757-19270	1757-19270	6079-18869	5736-16094

**The laboratory originally failed to report DEHP results. They went back and reevaluated the collected data and provided estimated results.*

Polycyclic Aromatic Hydrocarbons (PAHs) are products of incomplete combustion that can exist in particle and gas phases. PAHs usually occur as complex mixtures, not as single compounds. Of the 18 PAHs that are commonly produced during fires, seven were selected for analysis in this study (NIOSH, 1992). According to the International Agency for Research on Cancer (Thomas, 2010) benzo[a]pyrene is classified as Group 1-carcinogenic to humans; chrysene, and naphthalene as Group 2B-possibly carcinogenic to humans; and anthracene, fluoranthene, pyrene and phenanthrene as Group 3 –not classifiable as to its carcinogenicity to humans (Thomas, 2010).

Anthracene is obtained from coal tar and used in the production of dyes and organic chemicals. Anthracene was extracted from all fifty six specimens with the highest level on #35 at 1900 ug/kg. Sample #35 was removed from the armpit area of the outer shell. Fluoranthene is found in many combustible products. Fluoranthene was found in all fifty six specimens evaluated. The highest detection level of fluoranthene was detected on Sample #40 (outer shell crotch area) at 16,000 ug/kg. Phenanthrene is often used to make dyes, plastics, pesticides, explosives and drugs. Phenanthrene was detected on all fifty six specimens. The highest level of detection was found on specimen #40 (outer shell crotch area) at 8,600ug/kg on the outer shell crotch area. Pyrene is derived from coal tar and often used to make dyes. Pyrene was identified on all fifty six specimens. The highest level of detection was found on specimen #40 from the outer shell crotch area reporting 15,000 ug/kg. According to IARC's Monograph (2014), anthracene, fluoranthene, pyrene and phenanthrene are classified as Group 3 – not classifiable as to its carcinogenicity to humans.

Benzo (a) pyrene is a by-product of incomplete combustion or burning of organic (carbon-containing) items, e.g., cigarettes, gasoline, wood and as a by-product of many industrial processes. Benzo (a) pyrene is listed as a Group 1 carcinogen by the IARC Monograph (2014) and benzo (a) pyrene was extracted from all fifty six specimens evaluated. The highest level of benzo (a) pyrene was found in specimen #32 (armpit of outer shell) reported at 7400 ug/kg.

Chrysene is a natural constituent of coal tar and it is also found in a chemical used to preserve wood. Chrysene was detected in all 56 specimens evaluated from the

Philadelphia Fire Department. The highest detection level of chrysene at 11,000 ug/kg was present in specimen #40 (outer shell crotch area). The outer shell armpit and outer shell crotch areas had the highest levels of chrysene. Naphthalene is found in coal tar, moth balls, wood preserving, synthetic tanning agents, and insecticides. Analysis of the extracts of fifty three specimens reported that naphthalene was detected but less than the limit of quantification. The limit of quantification is referring to the smallest amount of analytical compound detected on each specimen. Three specimens were reported to have detection levels above the limit of quantification. The highest detection levels of naphthalene were reported on specimen #64 at 2,300ug/kg, which was removed from the crotch area of the thermal liner. The two additional specimens that reported levels of detection above the limits of quantifications were removed from the outer shell crotch area. Specimens #39 & #40 showed naphthalene levels of 300 ug/kg and 450 ug/kg. The thermal liner had the highest levels found on the crotch area. According to the IARC Monograph (2014), chrysene and naphthalene are classified as Group 2B – possibly carcinogenic to humans.

Plasticizers are also identified as phthalates and are found in many plastics. The outer shell armpit area, thermal liner collar area and outer wristlet that were not in direct contact with the skin had the highest levels of plasticizers.

Bis (2-ethylhexyl) phthalate (DEHP) is the most common of the class of phthalates which are used as plasticizers. Due to its wide dispersive use and concern for exposure to young children the use of DEHP and several other phthalates has been banned in the United States for use in children toys (Phthalates, 2014). DEHP is classified as a Group B2 carcinogen by the IARC Monograph (2014). DEHP has also been identified as a possible endocrine disruptor (Verotti, 2004.) DEHP was detected in all fifty six specimens at high levels. The highest detection level was on specimen #40 that was removed from the outer shell crotch area (not in direct contact with the skin) reported at 1,400,000 ug/kg.

Benzyl butyl phthalate (BzBP) is a phthalate and is often referred to as a plasticizer. Phthalates are typically found in numerous products including plastics, personal care products, packaging, and toys. BzBP was detected in all fifty six specimens; however, many of the detection levels were below the limit of quantification.

The highest detection level was on specimen #79 that was removed from the outside layer of the wristlet (not in direct contact with the skin) reported at 21,000ug/kg. Specimens removed from the outer layer of the wristlet had the highest detection levels of BzBP.

Dimethyl phthalate (DMP) is a plasticizer that has many uses. In addition to being used in plastics, DMP can be found in insect repellents, pesticides, safety glasses and many lacquers. DMP was detected in all fifty six specimens removed from the samples. All fifty six reported results for the samples were reported below the limit of quantification, resulting in the smallest amount of analyte that could be determined. Due to the low levels of detection on these samples, DMP is not considered to be a concern in Phase II of this study.

Di-n-octylphthalate (DNOP) is a plasticizer that is typically added to plastics to keep plastics soft or more flexible. DNOP is used in storage bags, wires and cables, carpet back coatings, floor tiles, and many adhesives. DNOP was detected on all fifty six specimens. The highest level of detection was reported as 36,000ug/kg that was removed from the outer shell crotch area from specimen #42. Overall, the outer shell had the highest detection levels.

Pentachlorophenol was at one time the most widely used biocide for pesticides in the United Sates. Pentachlorophenol is no longer available to the general public. Pentachlorophenol is often used in wood preservation and is continued to be used as an industrial pesticide. The main reason pentachlorophenol was selected was that an increase was detected in the air in simulated apartment fires when polyvinylchloride materials are present versus absent (Ruokojarvi, 2000). Pentachlorophenol was detected on all fifty six specimens removed from the samples of turnout gear. The detection levels were reported to be below the limit of quantifications meaning that there were minimum levels reported. Pentachlorophenol creates a cancer risk and can also result in long-term liver effects but for purposes of this study it is not a concern because of the minimum levels that were reported.

Polybrominated diphenyl ethers (PBDE) are often used in flame retardants and used on all firefighter turnout gear garments as a finish to make the garment itself flame retardant. The thermal liner had the PBDE’s highest levels in the collar area. The outer shell had the highest levels in the crotch area. The outer wristlet that was not in direct contact with the skin also had the highest level of PBDE's. Overall, the outer shell had the highest levels of detection.

Dibromo dibenzofuran (DBDBF) was detected in the neck samples from Pilot study, (inner and outer). It has been proposed that this substance is a thermolysis product of PBDE so it could be present during fires since PBDEs are in so many consumer items. All fifty six specimens removed from the samples of turnout gear were reported to have minimum levels of detection of DBDBF. These levels reported indicate the amounts detected are not of concern because they were minimal.

BDE 28 (2,4,4 Tribromodiphenyl ether) is a PBDE which is a class of synthetic chemicals that were introduced in the 1970's. PBDEs are typically added to products such as foam padding, textiles and plastics. BDE 28 (2,4,4 Tribromodiphenyl ether) is sometimes used as a flame retardant and is reported by the EPA that it has neurological behavior health effects. BDE 28 (2,4,4 Tribromodiphenyl ether) was detected on eleven specimens out of the fifty six removed from the samples of turnout gear. The remaining forty five specimens were reported to be minimum detection levels. Specimen #28 reported the highest detection level at 3476 ug/kg which was removed from the outer shell collar area. Overall, for purposes of this study, BDE 28 (2,4,4 Tribromodiphenyl ether) is not a concern.

BDE 100 (2,2,4,4,6 Pentabromodiphenyl ether) is also a PBDE often used as a flame retardant with similar properties and health effects of BDE 28. BDE 100 (2,2,4,4,6 Pentabromodiphenyl ether) was detected on fifty four of the fifty specimens. Two specimens reported that detection levels were below the minimum detection levels. Five specimens reported that the detection levels were less than the limit of quantification. Extremely high ug/kg was reported for BDE 100 especially for specimens that were removed from the outer shell collar area. Specimen #28 was reported to have detection levels at 560,095 ug/kg of BDE 100. Overall, the highest detection levels were on the outer shell of the turnout gear.

BDE 47 (2,2,4,4, Tetrabromodiphenyl ether) belongs to the chemical family of PBDEs and is typically found in plastics and pesticides. It has similar health effects of BDE 28 and BDE 100. BDE 47 (2,2,4,4, Tetrabromodiphenyl ether) was reported to have detection levels on all fifty six specimens removed from the turnout gear sample.

Specimen #57 was reported to have detection levels that were below the limit of quantification with <119 ug/kg which was located on the thermal liner and removed from the armpit area. Overall, the specimens removed from the outer shell collar area had the highest detection levels. Specimen #28 reported 1,503,921 ug/kg which was the highest detection level of BDE 47 (2,2,4,4, Tetrabrodiphenyl ether) from the fifty six samples. High levels of BDE-47 raises concern because this can be harmful to the neurological system causing long-term neurobehavioral effects. The outer shell had the highest detection levels overall.

BDE 153 (2,2,4,4,5,5 Hexabromophenyl ether) has properties similar to the other BDEs and health effects. Five specimens out of the fifty six specimens removed from the sample reported that the detection levels were below minimum detection levels. Nineteen specimens were reported to be below the limit of quantifications. The highest level of detection was reported to be from the outer shell collar area at 185,026 ug/kg. The outer shell collar are reported to have the highest detection levels of BDE 153 (2,2,4,4,5,5 Hexabromophenyl ether). The outer shell had the highest detection levels overall.

Octicizer® is a trade name for 2-ethylhexl diphenyl phosphate) is identified as a pale yellow liquid that is insoluble in water and often referred to as organophosphates. Organophosphates are susceptible to forming into highly toxic and flammable phosphine gases if they are in the presence of strong reducing agents, such as hydrides. The result of partial oxidation by the oxidizing agents can result in the release of toxic phosphorus oxides. This compound is a plasticizer and is combustible at a flash point of 435.2°F. Octicizer® was detected in all fifty six specimens and had a high detection level on specimen #70 that was removed from the wristlet that was in contact with the wrist at 302,409 ug/kg. Sample #43 from the outer shell crotch area was 179,864 ug/kg and sample #64 was 2072 ug/kg, meaning there was possible permeation from the outer shell fabric through to the thermal liner. The highest levels of detection were on the outer shell of the firefighter turnout gear. Levels of Octicizer® were detected in previous studies and in Phase I of this study and remain an area of concern.

N-octacosane is a C_{28} hydrocarbon and has little health hazard information available about this compound in particular. Further investigation indicates that it is in the class of paraffin waxes. Paraffin waxes mixtures of straight chain hydrocarbons having carbon numbers predominantly greater than C20 and are not classified as dangerous and are generally recognized as safe (GRAS) for use in food in the US and the EU (“EFSA”, p. 43, 2014). N-octacosane was detected on all fifty six specimens removed from the samples. The highest level of detection was reported for specimen #27 that was removed from the outer shell collar area at 57,130 ug/kg. Higher levels of detection were reported for the thermal liner armpit area specimens than what was reported for the outer shell armpit area specimens. Since no health effects have been identified this substance should be dropped from future studies. Overall, the highest levels were detected on the outer shell of the garment but remain not a concern for this study.

As a whole, the outer shell had the highest detection levels. The analysis shows that there could be permeation between the outer shell and the thermal liner but the detection levels are not as high on the thermal liner. The outside of the wristlet does have higher detection levels than the side of the wristlet that is in direct contact with the skin. The outer shell detection levels were mixed among the samples. The PAH’s were more prominent in the armpit area of the outer shell. The plasticizers were higher in the crotch area of the outer shell. The PBDE’s were higher on the collar area of the outer shell. The collar area of the thermal liner has the highest levels of all 21 compounds.

Specimens that were reported to have the highest level of detections of the twenty compounds selected for Phase II from the fifty six samples analyzed were selected to do a risk assessment. The following selected specimens were chosen: specimens #27 and #28 from the outer shell collar area, specimens #32 and #35 from the outer shell armpit area, specimen #40 from the outer shell crotch area, specimen #50 from the thermal liner collar area, specimen #64 from the thermal liner crotch area, specimen #70 from the wristlet layer in contact with the skin, and #79 from the wristlet outside layer not in contact with the skin. To be useful for risk assessment the analytical data is converted to units of ug/cm^2. This is achieved by calculating the basis weight of the fabric based on the measured weight of the fabric sample and the measured area of the sample recorded by the analytical lab. The typical basis weight unit is grams per square meter (gsm or g/m^2).

$$\text{mg/m}^2 = \text{reported ug/kg} \times 0.001 \text{ mg/ug} \times 0.001 \text{ kg/g} \times \text{basis weight (g/m}^2\text{)}$$

Table 4.8

Conversion of Analytical Data to Units Useful for Risk Assessment

Composition of Soils	Specimens mg/m2								
	#27	#28	#32	#35	#40	#50	#64	#70	#79
Anthracene	0.47	0.58	0.91	1.38	1.02	0.12	0.09	0.26	0.69
benzo (a) pyrene	0.94	0.8	3.2	4.35	2.35	0.19	0.18	0.42	2.29
butylbenzylphthalate	4.35	2.76	2.29	5.44	2.57	1.73	<MDL	<MDL	9.08
Chrysene	2.47	2.54	5.62	7.98	5.88	0.51	0.23	1.18	3.98
dimethylphthalate	<MDL	2.47	2.29	<MDL	2.14	0.48	<MDL	<MDL	<MDL
Bis (2-ethylhexyl) phthalate	130	68.2	36.7	76.5	749	30.9	5.59	55	134
Fluoranthene	3.99	4.5	3.98	6.02	8.56	0.61	0.3	1.44	3.46
Naphthalene	<MDL	0.25	0.23	<MDL	0.24	0.05	1.23	<MDL	<MDL
di-n-octylphthalate	7.26	5.44	3.72	24	6.42	2.17	0.36	3.16	7.35
pentachlorophenol	<MDL	2.47	2.33	<MDL	2.19	0.51	<MDL	<MDL	<MDL
phenanthrene	1.96	3.12	2.72	3.41	4.6	0.44	0.28	1.07	1.08
Pyrene	3.41	3.99	3.42	5.15	8.02	0.51	<MDL	1.39	3.42
Dibromo dibenzofuran	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
BDE 28	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Octicizer®	79.2	77.9	48.68	53.1	76.33	12.1	1.11	161.7	23.3
BDE 47	2.59	1092	1.7	3.15	4.27	0.72	0.17	1.71	0.36
PCB 194	<MDL	0.12	0.11	<MDL	0.11	<MDL	<MDL	<MDL	<MDL
n-octacosane	41.5	5.01	5.46	7.7	5.27	8.81	54.09	6.96	5.7
BDE 100	0.6	406	0.47	0.86	1.12	0.08	0.03	0.39	<MDL

Table 4.8

Conversion of Analytical Data to Units Useful for Risk Assessment (continued)

Composition of Soils	Specimens mg/m2								
	#27	#28	#32	#35	#40	#50	#64	#70	#79
BDE 99	2.61	1494	2.19	3.45	5.77	0.56	0.17	1.65	0.41
BDE 153	<MDL	134	0.21	<MDL	0.46	<MDL	<MDL	<MDL	<MDL

To complete the risk assessment the mass per fabric area needs to be integrated into a dermal exposure assessment. In Table 4.8, was used to identify the highest potential contamination level for the outer layer and thermal liner and these results are then used for the risk assessment. Two types of risk assessments were performed; one for non-cancer endpoints and one for cancer endpoints. This is necessary since cancer is assessed over the lifetime and non-cancer effects are assessed based on a daily exposure. For the assessments a worst case approach was to assume $1m^2$ of the garment transferred the extractable amount to the skin. Garments would typically be $2 – 3m^2$ of fabric and the garment is unlikely to be 100% soiled. This is extremely conservative since the analytical methods involved solvent extraction to establish what was present on the fabric rather than determining what would be extractable from sweat extraction. Once the substance is transferred to the skin the amount that can dermally absorb must be calculated. The dermal absorption factor is the percent dermal absorption divided by 100. The percent dermal absorption is assumed to be 100% unless there is published information indicating less than 100. The EPA has reported that dermal absorption for PBDEs is 3% (EPA, 2010). The PAHs have a dermal absorption of 20% based on the Health Canada Relative Dermal Absorption Factors issued 2007 (Health Canada, 2007). The Australian authorities have indicated that dimethyl phthalate has a dermal absorption of 10% and it is the most water soluble phthalate so the other phthalates would be expected to absorb less since they are less water soluble so 10% was used as a worst case for all the phthalates (Dimethyl phthalate (DMP) Factsheet, 2014). EPA default guidance for pentachlorophenol dermal absorption is 24.4% based on in vivo studies, and 30% was used for dibromo dibenzofuran based on in vivo studies for similar type compounds (INCHEM). EPA Region III indicated that PCBs have a dermal absorption of 6% (EPA, 2014). This information is reflected in Table 4.9. Where estimated dermal exposure is calculated as follows:

$$\text{Dermal absorbed Dose (DAD)} = \text{skin loading } (mg/m^2) \times SA \times DAF = mg/day$$

Equation 2 where:

DAD = estimated dermal dose for exposure scenario (mg/day)

Skin loading = mass on skin (mg/m^2)

SA = surface area of skin contact, use 1 m^2 for scenario

DAF = Substance specific dermal absorption factor, or % absorption divided by 100 Only one significant number is reported for dermal exposure since there is considerable variability in the analytical results and the potential exposure.

Table 4.9

Dermal Exposure Estimates based on highest loading detected for Outer layer and Thermal Liner

Composition of Soils	Highest loading detected for Outer layer (mg/m2)	Highest loading detected for Inner layer (mg/m2)	Dermal Absorption Factor	Estimated Dermal Exposure based on Outer layer (mg/day)	Estimated Dermal Exposure based on Inner layer (mg/day)
Anthracene	1.02	0.12	0.2	0.2	0.02
benzo (a) pyrene	4.35	0.19	0.2	0.9	0.04
Butylbenzylphthalate	5.44	1.73	0.1	0.5	0.2
Chrysene	7.98	0.51	0.2	0.8	0.1
Dimethylphthalate	2.47	0.48	0.1	0.2	0.05
Bis (2-ethylhexyl) phthalate	130	30.9	0.1	13	3
Fluoranthene	8.56	0.61	0.2	2	0.1
Naphthalene	0.24	1.23	0.2	0.5	0.2
di-n-octylphthalate	7.26	2.17	0.1	0.7	0.2
Pentachlorophenol	2.47	0.51	0.24	0.6	0.1
Phenanthrene	4.6	0.44	0.2	0.9	0.09
Pyrene	8.02	0.51	0.2	2	0.1
Dibromo dibenzofuran	<MDL	<MDL	0.3	minimal	Minimal

*no data on dermal absorption was found so worst case of 100% was assumed

Table 4.9

Dermal Exposure Estimates based on highest loading detected for Outer layer and Thermal Liner (continued)

Composition of Soils	Highest loading detected for Outer layer (mg/m2)	Highest loading detected for Inner layer (mg/m2)	Dermal Absorption Factor	Estimated Dermal Exposure based on Outer layer (mg/day)	Estimated Dermal Exposure based on Inner layer (mg/day)
BDE 28	<MDL	<MDL	0.03	minimal	Minimal
Octicizer®	79.2	12.1	1*	79	12
BDE 47	1092	0.72	0.03	33	0.02
PCB 194	0.12	<MDL	0.06	0.007	Minimal
n-octacosane	41.5	54.09	1*	42	54
BDE 100	406	0.08	0.03	12	0.002
BDE 99	1494	0.56	0.03	45	0.02
BDE 153	134	<MDL	0.03	4	Minimal

*no data on dermal absorption was found so worst case of 100% was assumed

The dermal exposure estimates from Table 4.9 are divided by the appropriate health benchmark to estimate the Risk Characterization Ratio (RCR). RCR should be less than 1 to indicate no significant risk of health hazards. The health benchmarks were primarily selected from the EPA Integrated Risk Information System (IRIS) (EPA, 2014). The oral reference dose (RfD) was the preferred selection for non-cancer risks. The substances that did not have an RfD in IRIS are detailed below. A heath benchmark for Octicizer® was found in a risk assessment performed by the UK (Environmental Risk Evaluation Report for CAS 1241-94-7, 2009.) A health benchmark for PCBs was found from the Agency for Toxic Substances & Disease Registry (ASTDR). The ASTDR has a list with recommended minimal risk levels (MRL) for which daily exposures should cause no appreciable effects (ASTDR, 2014). No health benchmark was found for phenanthrene so it was assigned the lowest value from comparative PAHs (Group 3) which was pyrene. No health benchmark was found for dimethyl phthalate and di-n-octyl phthalate so they were assigned the lowest value from the comparative phthalates for conservatism which was bis(ethylhexyl) phthalate. The health benchmarks are typically reported as mg/kg/day for oral toxicity and for this assessment the body weight of 80 kg was used to convert the health benchmarks to units of mg/day (EPA Exposure Factor Handbook, 2011). Once a substance has dermally absorbed it is available for systemic exposure which is assumed to be equivalent to the oral exposure route for this assessment. The non-cancer endpoint risk characterization is presented in Table 4.10.

Table 4.10

Risk Characterization for Non Cancer Endpoints

Composition of Soils	Est. Dermal Exposure based on Outer layer (mg/day)	Est. Dermal Exposure based on Thermal Liner (mg/day)	Health Benchmark for Non Cancer mg/day	Risk Characterization Ratio for Outer layer	Risk Characterization Ratio for Thermal Liner
Anthracene	0.2	0.02	24	0.01	0.001
benzo (a) pyrene	0.9	0.04	Assessed for cancer	not applicable	not applicable
Butylbenzylphthalate	0.5	0.2	16	0.03	0.01
Chrysene	0.8	0.1	Assessed for cancer	NA	NA
Dimethylphthalate	0.2	0.05	1.6	0.13	0.03
Bis (2-ethylhexyl) phthalate	13	3	1.6	8.13	1.88
Fluoranthene	2	0.1	3.2	0.63	0.03
Naphthalene	0.5	0.2	1.6	0.31	0.13
di-n-octylphthalate	0.7	0.2	1.6	0.44	0.13
Pentachlorophenol	0.6	0.1	0.39	1.54	0.26
Phenanthrene	0.9	0.09	2.4	0.38	0.04
Pyrene	2	0.1	2.4	0.83	0.04
Dibromo dibenzofuran	minimal	Minimal	None found	NA	NA
BDE 28	minimal	Minimal	0.008	NA	NA
Octicizer®	79	12	2.4	33	5.0
BDE 47	33	0.02	0.008	4125	2.5
PCB 194	0.007	Minimal	0.02	0.35	NA
n-octacosane	42	54	Not hazardous	NA	NA
BDE 100	12	0.002	0.008	1500	0.25
BDE 99	45	0.02	0.008	5625	2.50
BDE 153	4	Minimal	0.008	500	NA

The risk characterization for the non-cancer endpoints indicate that there is potential for health effects based on the conservative scenario that assumes the amount extracted by solvent transfers to the skin on a daily basis when firefighters wear the turnout gear. The results also indicate the outer layer is more contaminated than the thermal liner but it likely demonstrates that the contamination does migrate inwards. The substances of greatest concern were the polybrominated diphenyl ethers (PBDEs) as BDE-47 and BDE-99 had RCRs of greater than 1 for the thermal liner. Bis (2-ethylhexyl) phthalate also had a RCR of greater than 1 for the thermal liner. Octicizer® had a RCR greater than 1 for the thermal liner but this is based on using a dermal absorption of 100% which is likely an overestimation.

To assess for the risk of cancer the lifetime of the firefighter is considered which is assumed to be 70 years. For the Phase II exposure scenario it is assumed that the firefighter would wear the turnout gear 3 days a week, 24 hours each day for 50 weeks per year over the span of their career, which considered 40-years for worst case. These same defaults for lifetime, worker days/year and career period are defined in California Proposition 65 Law for assessing exposure to carcinogens (Title 27, 2002). The assumption was made that the firefighter would be hot and sweaty from the conditions of the firefighting environment enabling the sweat to mobilize substances for dermal absorption.

This scenario was chosen because it was believed to be a conservative approach to analyze the use of the turnout gear for a firefighter who has chosen firefighting as their lifelong career path. This could increase or decrease depending on how often the firefighter responds to calls. The dermal exposure for the carcinogens is estimated as follows:

$$\text{Lifetime dermal exposure} = \frac{\text{DAD (mg/day)} \times \text{days in gear/wk} \times \text{wks worked/yr} \times \text{yrs worked}}{\text{365 days/year} \times \text{70 years}}$$

$$= \frac{\text{mg/day} \times \text{2 days/week} \times \text{50 wks/year} \times \text{40 yrs}}{\text{25550 days}} = \text{mg/day} \times 0.16$$

Since cancer is a non-threshold effect the risk assessment is performed based on a defined risk factor such as 1 in 100,000 or 1 in 1,000,000 cases of cancer per population.

The health benchmark is given as a slope factor that has inverse units of exposure (day/mg based on an 80 kg firefighter):

Risk Characterization =

lifetime dermal exposure (mg/day) x slope factor (day/mg) x risk factor (100,000)

For this assessment the risk factor was defined as 1 in 100,000. Again results greater than one indicates a risk of cancer based on the scenario used for the risk assessment. The cancer slope factors were obtained from the EPA IRIS system in units of (day/kg/mg). The approach is defined in the EPA Guidelines for Carcinogen Risk Assessment (EPA, 2005). The risk characterization for cancer is presented in Table 4.11.

Table 4.11

Risk Characterization for Carcinogen Endpoints based

Composition of Soils	Estimated Lifetime Dermal Exposure based on Outer layer (mg/day)	Estimated Lifetime Dermal Exposure based on Thermal Liner (mg/day)	IRIS Cancer Slope Factor (day/mg)	Risk Characterization Ratio for Outer layer	Risk Characterization Ratio for Thermal Liner
benzo (a) pyrene	0.144	0.0064	0.09	1296	58
Chrysene	0.128	0.016	0.00009	1	0.1
Bis (2-ethylhexyl) phthalate	2.08	0.48	0.0002	42	10
Naphthalene	0.08	0.032	0.00009	1	0.3
pentachlorophenol	0.096	0.016	0.0015	14	2

*based on a cancer risk of 1 in 100,000

For those who work in the firefighter industry for at least forty years of their life, fighting 100 fires per year, the following substances could potentially be a cancer risk: benzo (a) pyrene, bis (2-ethylhexyl) phthalate and pentachlorophenol. This is based on assuming that the amount released by solvent extraction could all reach the skin each day of use which is extremely conservative. The results also indicate that the outer layer is more contaminated than the thermal liner but it likely demonstrates that the contamination does migrate inwards. The EPA IRIS system was consulted to identify the specific health effect associated with the substances that showed risk. Note that Octicizer® is not in IRIS and the previously mentioned UK environmental risk assessment was used. The effects are listed in Table 4.12.

Table 4.12

Substances Identified of Potential Concern in Thermal Liner

Substance	Health Effect
Bis (2-ethylhexyl) phthalate	Cancer, possible endocrine disruptor
Octicizer®	Possible liver effects
BDE 47 (PBDE class)	Neurobehavioral effects
BDE 99 (PBDE class)	Neurobehavioral effects
benzo (a) pyrene (PAH class)	Cancer (stomach and skin cancer in animals)
Pentachlorophenol	Cancer (liver cancer and Non-Hodgkin's Lymphoma in humans)

The PBDEs are of concern since they accumulate in the body (EPA, 2010 – An Exposure Assessment of Polybrominated Diphenyl Ethers), the calculations used to determine whether the health benchmarks recommended for each compound were based off a conservative approach similar to that of pilot study. There are variables that would affect these calculations including time spend in the field fighting fires, long term exposure to these soils, and the years spent in this particular career.

Discussion

The overall objective of this research was to identify the composition of soils on the firefighter turnout gear from the Philadelphia Fire Department. The research objectives of this study were as follows:

1. To visually identify the areas of heavy soiling on turnout gear (coats and pants).

In Phase I, three sets of turnout gear were obtained for a total of six pieces; three turnout gear coats and three turnout gear pants. Each set of gear was carefully handled, photographed and visually inspected to document any holes, tears, and the overall soiling of the garment according to NFPA 1851 Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting, 2014 Edition. Visual soiling was apparent on all turnout gear evaluated. The gear showed changes within the material's texture due to charring, unidentified substances on the gear, and pilling caused by abrasion, tears and holes. There were various locations on the outer shell coats and pants that showed visible signs of soiling including the collar, crotch, armpit and wrist areas. The moisture barrier of the coats and pants showed visible evidence of soiling on the collar, armpit, crotch and wrist area; what appeared to be perspiration stains were very prominent on the collar, the crotch and the armpit locations. The thermal liner was most soiled on the collar, crotch, armpit and wrist area. In summary for Phase I, the following areas were visually identified as heavily soiled areas during an initial overall inspection process when the turnout gear was received at the University of Kentucky: collar, armpit, crotch, and wrist.

In Phase II, seven turnout gear coats and seven turnout gear pants were selected for evaluation based on repair and wash history of the garments. Once the samples arrived at the University of Kentucky, each set of gear was carefully inspected. The gear was photographed and visually inspected to document any holes, tears, and the overall soiling of the garment. Visual soiling was apparent on all seven sets of the turnout gear. All gear showed changes within the material's texture due to charring, unidentified substances on the gear, and pilling caused by abrasion, tears and holes. Like Phase I, there were various locations on the outer shell coats and pants that showed visible signs of soiling including the collar, crotch, armpit and wrist areas. The overall garment, by looking at the outer shell, appeared to be heavily soiled. The moisture barrier showed visible evidence of soiling on the collar, armpit, crotch and wrist area; what appeared to be perspiration stains were very prominent on the collar, the crotch and the armpit locations. The thermal liner was most soiled on the collar, crotch, armpit and wrist area. The wristlet from the wrist area was carefully inspected and examined because it was so heavily soiled. The nature of this material content is knitted and much different than that which makes up the remainder of the turnout gear suit. In summary for Phase II, the following areas were identified as heavily soiled areas: collar, armpit, inner wristlet (in direct contact with the skin), outer wristlet (not in direct contact with the skin), and crotch.

2. To evaluate the composition of soil using analytical lab procedures.

In the pilot study, the compositions of soils on the hoods were evaluated by DuPont Experimental Station in Wilmington, Delaware. A total of ten Nomex® hoods were evaluated: one new hood which served as the control and nine used hoods. Twenty one compounds and thirty four trace metals were identified. The trace metals identified were on both the new control hood and the nine used hoods.

In Phase I, DEHP, Di-n-Octyl-phthalate, Fluoranthene, Octicizer®, and Octacosane were identified. DEHP, Di-n-Octyl-phthalate and Octicizer® are plasticizers. Plasticizers are typically additives that allow materials to have more flexibility. DEHP is most used in the production of PVC and vinyl chloride resins, where it is added to plastics to make them flexible. Di-n-Octyl-phthalate is a colorless plasticizer that has a mild odor ("Cameo Chemicals", 2014). As a liquid form it can easily penetrate through fabrics and can produce mild skin irritation. Di-n-Octyl-phthalate is often used in the manufacturing process of a variety of plastics and coating products. Octicizer® is a trade name for 2-Ethylhrxyl Diphenyl Phosphate and is identified as a liquid that is insoluble in water. Octicizer® is often referred to as organophosphates which are susceptible to forming highly toxic and flammable phosphine gases if they are in the presence of strong reducing agents, such as hydrides ("Cameo Chemicals", 2011). Octicizer® may produce dangerous vapors and is considered harmful when ingested or inhaled ("EPA", 2014). Fluoranthene and Octacosane are known as polycyclic aromatic hydrocarbons (PAH). PAH's are organic compounds that only contain carbon and hydrogen. PAH's are often found in fossil fuels such as coal and tar. The EPA has classified fluoranthene as a probable human carcinogenic compound (Wikipedia, 2014). Octacosane is known as a waxy solid that is insoluble in water. Octacosane is not linked to any potentially hazardous health effects but does cause irritation to the eyes, skin and respiratory tract.

In Phase II, a total of twenty one compounds were identified. These included groups of PAH's, plasticizers, PVC, PBDE's, P043, PCB's and hydrocarbons. The PAH's identified on the turnout gear were anthracene, benzo (a) pyrene, chrysene, fluoranthene, naphthalene, phenanthrene, and pyrene. The plasticizers identified on the turnout gear were butylbenzylphthalate, dimethlphthalate, di-n-octykphthalate and DEHP. Pentachlorophenol as a PVC. Multiple PBDE's were identified that included DBDBF, PBDE-28, PBDE-100, PBDE-47, PBDE-153, and PBDE-99. Octicizer® as P043 was identified, also known as a flame retardant, a PCB-194 a polychlorinated biphenyl, and octacosane a hydrocarbon.

3. To identify the location of potentially hazardous materials on soiled firefighter turnout gear in the context of the areas where dermal absorption is high.

The pilot study identified numerous trace metals and soils that are potentially hazardous to the firefighter wearing the hood which covers the head and part of the face. Phase I identified that the outer shell had higher levels of the detection of soils than the thermal liner. Of the soils that were identified in Phase I, the armpit and crotch areas were of most concern. Four compounds were identified on the samples from the firefighter turnout gear including DEHP, fluoranthene, Octicizer®, and octacosane. The samples were removed from the collar, armpit, crotch and wrist areas of both the outer shell and thermal liner. These areas are known to have high dermal absorption levels and were selected based on the Maibach Study (Maibach, 1971).

Based on the results from Phase II, the crotch area was identified as a location where PAH's are the most prominent on both the outer shell and thermal liner. The location where plasticizers were most relevant was the crotch area of the outer shell and the collar area of the thermal liner. PBDE's had the highest levels of detection on the collar area of both the outer shell and thermal liner. Flame retardants were most prominent on the crotch area of the outer shell and collar area of the thermal liner. Hydrocarbons were identified the most on the collar of both the outer shell and the thermal liner. Overall, the PAH's, PBDE's, flame retardants, and hydrocarbons were more prevalent on the outside wristlet than the side in contact directly with the skin.

4. To determine the dangers of exposures to the hazardous materials by evaluating the quantity of hazardous materials and compared this quantity to the recommended exposure limits.

Based on the results of the pilot study, because dermal exposure was evaluated from the extraction results to complete a risk assessment of trace metals on the hoods it was determined that the following trace metals are considered hazardous: Aluminum (Al), Chromium (Cr), Arsenic (As), Tin (Sn), Antimony(Sb) and Lead (Pb). Since such an aggressive extraction method was used, these six trace metals were further reviewed. The health benchmarks selected for aluminum (Al) and chromium (Cr) were identified as excessively conservative. Al has a dietary daily allowable dose of 1.6mg to 13mg per day and no regulatory body has identified a level of concern for Al. The Cr health benchmark used for the assessment was based on Chromium (VI). Cr (III) is the form typically found in the environment and consumer products rather than Cr (VII) which is used in manufacturing. The extraction method does not distinguish between the two forms [Cr (VI) and Cr (III)]. The health benchmark for Sn assumes all the Sn was in the form of tribuyltin oxide which again is unlikely since this substance has been mainly used as a marine antifouling agent for boats. This reduces the list of metals to arsenic for carcinogenic risk.

A risk assessment was not completed for Phase I because Phase I was mainly to identify effective analytical procedures, so no exposure limits of the soils identified was evaluated. Phase II results concluded that seventeen hazardous materials were identified in this study and considered to be potentially hazardous materials because they are higher than recommended exposure limits. Based on both the outer layer and thermal liner results the potentially hazardous materials identified are as follows: Benzo(a)pyrene, pentachlorophenol, Octicizer®, BDE 47, BDE 100, BDE 99 and BDE 153. The risk assessment was completed and determined that of the 21 substances evaluated, seven of them are identified as substances that can potentially cause adverse health effects such as cancer, and damage to the endocrine nervous and liver systems.

Overall, all areas that were identified to be areas of high dermal absorption are of concern. The levels found from the composition of soils in the pilot study, Phase I and Phase II are considered to be harmful to the firefighter due to the areas of exposure. The potentially hazardous materials and toxins have been identified in areas that are considered to be high dermal absorption zones.

5.) To evaluate results to determine if they correlate to the use of the turnout gear.

The wash history that was provided for Phase II turnout gear showed some relationships between the last time since the turnout gear was laundered and the soil level. Specimens #28, #35, #49, #56, #70 and #77 were taken from garment number D's coat which visually was the worst soiled out of all of the sets and had not been laundered since 2011. Specimen #28 had high levels of butylbenzylphthalate, chrysene, dimethylphthalate, Bis (2-ethylhexyl) phthalate, Di-n-octylphalate, pentachlorophenol, phenanthrene, pyrene, Octicizer®, BDE 47, BDE 99, BDE 153, BDE 100 and octacosane which was removed from the collar area and considered to be a potential risk for dermal absorption according to the risk assessment calculations. Specimen #35 had high levels of anthracene, benzo (a) pyrene, butylbenzylphthalate, chrysene, Bis (2-ethylhexyl) phthalate, Di-n-octylphalate, fluoranthene, pentachlorophenol, phenanthrene, pyrene, Octicizer®, BDE 47, BDE 99, and octacosane.

Chapter Five

Conclusions

The purpose of this research was to identify the composition of soils on firefighter turnout gear from the Philadelphia Fire Department and to determine which soils contain hazardous materials. The research was split into a pilot study and two phases: Phase I and Phase II. Soils were identified on specimens removed from Philadelphia Fire Department turnout gear and evaluated to determine the potential health risk that firefighters are faced with.

The pilot study analyzed hoods that were considered to be worst case scenario because they aren't typically laundered after each use. They are severely soiled because of the multiple times they are worn without washing. A control hood and nine used hoods were sampled. The control hood provided a base for what was present on the hoods before being exposed to any soils and/or hazardous materials. The pilot study identified hazardous materials and multiple trace metals. A risk assessment was completed on the trace metals identified in the study to help identify any potential health risks to the firefighters. Based on the results of analyzing the hoods the majority of the compounds identified in the soils on the hoods in the pilot study are heavy metals. A suggestion would be to wash the hoods in water and detergent which should remove most of the chemicals, as well as metals and other inorganics.

Phase I mainly focused on the selection of the analytical methods to help identify the composition of soils on the Philadelphia firefighter turnout gear. One set of gear was selected based on the overall visual amount of soiling. Five compounds were selected to be analyzed based on previous research from the Kingsland study completed in 2003 and an increased interest in PAH's. In order to better understand the composition of soils the five compounds that were selected and analyzed in Phase I are as follows: Octicizer® (2-ethylhexyl diphenyl phosphate), bis (Ethylhexyl) phthalate, Di-n-Octyl-phthalate, Octacosane and Fluoranthrene. Twenty four specimens were removed from one set of turnout gear provided by the Philadelphia Fire Department from areas that were thought to be of high dermal absorption. The samples were sent to DuPont in Wilmington, Delaware to analyze and identify if the five compounds identified above were present. Of the five compounds that were analyzed in Phase I, Di-n-Octyl-phthalate had no detection levels present. Di-n-Octyl-phthalate which is known to affect the human organ systems is not ruled out completely because it has been found in previous studies but for purposes of this research, it was not thought to be a concern. Octicizer® (2-ethylhexyl diphenyl phosphate), bis (Ethylhexyl) phthalate, Octacosane and Fluoranthrene levels were identified in Phase I and considered during the selection of Phase II compounds.

Phase II was an expansion of Phase I to further investigate the composition of soils found on firefighter turnout gear from the Philadelphia Fire Department. When selecting the samples to be evaluated for Phase II, documented wash history was mandatory illustrating that the selected samples had been laundered at least one time per year. The number of soils selected for analysis in Phase II was expanded to focus on soils in addition to the five compounds in Phase I. To better evaluate the composition of soils on the Philadelphia Fire Departments firefighter turnout gear, twenty compounds were chosen based on the concern that they could be potentially hazardous if orally or dermally exposed. The compounds selected to further evaluate the composition of soils are as follows: anthracene, benzo(a) pyrene, chrysene, fluoranthrene, naphthalene, phenanthrene, pyrene, BzBP Benzyl butyl phthalate, Dimethyl phthalate, di-n-octylphthalate, Pentachlorophenol, Dibromo dibenzofuran, BDE 28 (2,4,4 Tribromodiphenyl ether), BDE 28 (2,2,4,4,6 Pentabromodiphenyl ether), BDE 47 (2,2,4,4, Tetrabromodiphenyl ether), BDE 153 (2,2,4,4,5,5 Hexabromophenyl ether), Octicizer® (2 ethylhexl diphenyl phosphate), PCB 194 (2,2,3,3,4,4,5,5 Octachlorobiphenyl), and N-Octacosane.

The overall objective of this research was to identify the composition of soils on the firefighter turnout gear from the Philadelphia Fire Department. The research objective to visually identify the areas of heavy soiling on turnout gear (coats and pants) found that *v*isual soiling was apparent on all three sets of the turnout gear. All three sets of gear showed changes within the materials texture due to charring, unidentified substances on the gear, pilling cause by abrasion, tears and holes. There were various locations on the outer shell coats and pants that showed visible signs of soiling including the collar, crotch, armpit and wrist areas. The moisture barrier of the coats and pants showed visible evidence of soiling on the collar, armpit, crotch and wrist area; what appeared to be perspiration stains were very prominent on the collar, the crotch and the armpit locations.

The thermal liner was most soiled on the collar, crotch, armpit and wrist area. In summary for Phase I, the following areas were visually identified as heavily soiled areas during an initial overall inspection process when the turnout gear was received at the University of Kentucky: collar, armpit, crotch, and wrist.

In Phase II, visual soiling was apparent on all seven sets of the turnout gear. All seven sets of gear showed changes within the materials texture due to charring, unidentified substances on the gear, pilling cause by abrasion, tears and holes. Like Phase I, there were various locations on the outer shell coats and pants that showed visible signs of soiling including the collar, crotch, armpit and wrist areas. The overall garment by looking at the outer shell appeared to be heavily soiled. The moisture barrier of the coats and pants showed visible evidence of soiling on the collar, armpit, crotch and wrist area; what appeared to be perspiration stains were very prominent on the collar, the crotch and the armpit locations. The thermal liner was most soiled on the collar, crotch, armpit and wrist area. The wristlet from the wrist area was carefully inspected and examined because it was so heavily soiled. The nature of this material content is much different than that, which makes up the remainder of the turnout gear suit. In summary for Phase II, the following areas were identified as heavily soiled areas: collar, armpit, inner wristlet (in direct contact with the skin), outer wristlet (not in direct contact with the skin), and crotch.

The second research objective was to evaluate the composition of soil using analytical lab procedures. In the pilot study, twenty one compounds and thirty four trace metals were identified. The trace metals identified were on both the hood used as a control and the nine used hoods.

In Phase I, DEHP, Di-n-Octyl-phthalate, Fluoranthene, Octicizer®, and Octacosane were identified. DEHP, Di-n-Octyl-phthalate and Octicizer® are plasticizers. In Phase II, a total of twenty one compounds were identified. These included groups of PAH's, plasticizers, PVC, PBDE's, P043, PCB's and hydrocarbons. The PAH's identified on the turnout gear were anthracene, benzo (a) pyrene, chrysene, fluoranthene, naphthalene, phenanthrene, and pyrene. The plasticizers identified on the turnout gear were butylbenzylphthalate, dimethlphthalate, di-n-octykphthalate and DEHP. Pentachlorophenol as a PVC. Multiple PBDE's were identified that included DBDBF, PBDE-28, PBDE-100, PBDE-47, PBDE-153, and PBDE-99. Octicizer® as P043 was identified, also known as a flame retardant, a PCB-194 a polychlorinated biphenyl, and octacosane a hydrocarbon.

The third research objective was to identify the location of potentially hazardous materials on soiled firefighter turnout gear in the context of the areas where dermal absorption is high. The pilot study identified numerous trace metals and soils that are potentially hazardous to the firefighter wearing the hood which covers the head and part of the face. Phase I identified that the outer shell had higher levels of the detection of soils than the thermal liner. Of the soils that were identified in Phase I, the armpit and crotch areas were of most concern. Four compounds were identified on the samples from the firefighter turnout gear including DEHP, fluoranthene, Octicizer®, and octacosane. The samples were removed from the collar, armpit, crotch and wrist areas of both the outer shell and thermal liner. These areas are known to have high dermal absorption levels and were selected based on the Maibach Study (Maibach, 1971). Based on the results from Phase II, the crotch area was identified as a location where PAH's are the most prominent on both the outer shell and thermal liner.

The fourth research objective was to determine the dangers of exposures to the hazardous materials by evaluating the quantity of hazardous materials and compared this quantity to the recommended exposure limits. Based on the results of the pilot study, because dermal exposure was evaluated from the extraction results to complete a risk assessment of trace metals on the hoods it was determined that the following trace metals are considered hazardous: Aluminum (Al), Chromium (Cr), Arsenic (As), Tin (Sn), Antimony(Sb) and Lead (Pb). The health benchmarks selected aluminum (Al) and chromium (Cr) were identified as unreasonable. A risk assessment was not completed for Phase I because Phase I was mainly to identify effective analytical procedures, so no exposure limits of the soils identified was evaluated. Phase II results concluded that seventeen hazardous materials were identified in this study and considered to be potentially hazardous materials because they are higher than recommended exposure limits.

Overall, all areas that were identified to be areas of high dermal absorption are areas of concern. The levels found from the composition of soils in the pilot study, Phase

I and Phase II are considered to be harmful to the firefighter due to the areas of exposure. The potentially hazardous materials and toxins have been identified in areas that are considered to be high dermal absorption zones.

The final research objective was to evaluate results to determine if they correlate to the use of the turnout gear. The wash history that was provided for Phase II turnout gear showed some correlation between the last time since the turnout gear was laundered and the soil level. Garment number four's coat that had specimens #28, #35, #49, #56, #70 and #77 removed from it was visually the worst soiled out of all of the sets and had not been laundered since 2011. Specimen #28 had high levels of butylbenzylphthalate, chrysene, dimethylphthalate, Bis (2-ethylhexyl) phthalate, Di-n-octylphalate, pentachlorophenol, phenanthrene, pyrene, Octicizer®, BDE 47, BDE 99, BDE 153, BDE 100 and octacosane which was removed from the collar area and considered to be a potential risk for dermal absorption according to the risk assessment calculations. Specimen #35 had high levels of anthracene, benzo (a) pyrene, butylbenzylphthalate, chrysene, Bis (2-ethylhexyl) phthalate, Di-n-octylphalate, fluoranthene, pentachlorophenol, phenanthrene, pyrene, Octicizer®, BDE 47, BDE 99, and octacosane. This garment had not been laundered since 2011, was extremely soiled according to the visual assessment and had high levels present during the analysis for soils.

All of the other garments were consistent in levels of soiling compared to the wash history provided. It could be assumed that the increased levels of soiling could be associated with the number of times the garment is laundered.

Limitations

The selection of the sample size was one limitation of this study. Sample size was limited by funding and criteria set forth for inclusion in the study. Turnout gear included in the study had to have been laundered at least once per year and to have been in service between three to five years. Specimens removed from the sample for evaluation were only removed from locations where dermal absorption was thought to be high risk therefore not giving an overview of what the composition of soils is on the entire firefighter turnout gear. Another limitation of this study would be the limited information on the history of the garments regarding cleaning cycles, use and the environment in which the wearer was fighting fires. The way the turnout gear is stored by the firefighter can also be a concern; if not properly store it creates degradation of materials and cross contamination of chemicals from one set of gear to another.

Recommendations for Future Research

Based upon the results of this research, it is recommended that further analysis be completed on PBDEs and flame retardants to identify their short and long-term health hazards to the firefighter. Due to the conservative approach of calculating ones cancer risk for being exposed to PBDEs and flame retardants, they should be considered for future studies because of their potential concern. Further research would allow the firefighter to be aware of potential health concerns and be better equipped to protect themselves. This may result in more proactive cleaning and maintenance of the turnout gear.

A more detailed background on use and cleaning history is recommended. This would allow the researcher to gain a better understanding of the removal process during washes. A monitored study of the firefighter would also be helpful to analyze whether the composition of soils that they are exposed to on a daily basis has shown signs of health issues. A final recommendation is to conduct a similar study with firefighter turnout gear that has never been used and monitor and analyze the gear on a regular basis throughout its life cycle from beginning until retired. This would educate us on what the firefighter is exposed to over the life of the gear and to what detection levels they would be exposed.

Appendix A

Definition of Terms

Anthracene – is one of a group of chemicals called polycyclic aromatic hydrocarbons (EPA, 2012).

Benzo (a) pyrene – is a polycyclic aromatic hydrocarbon found in coal tar (EPA, 2012).

Bis (2-ethylhexyl) phthalate- is used in the production of polyvinyl chloride and exhibits low toxicity (EPA, 2014).

Butylbenzylphthalate- is a phthalate and an ester of phthalic acid, benzyl alcohol and butanol (EPA, 2013).

Chrysene- is a polycyclic aromatic hydrocarbon and is found in creosote which is a chemical used to preserve wood (EPA, 2014).

Cleaning – The act of removing soils and contaminants from ensembles or ensemble elements by mechanical, chemical, thermal, or combined processes (National Fire Protection Association, p. 9, 2014).

Contamination/Contaminated – The process by which ensembles and ensemble elements are exposed to hazardous materials, body fluids, or chemicals, biological agents, and radiological particulates (CBRN) terrorism agents (National Fire Protection Association, p. 9, 2014).

Dimethylphthalate- is a phthalate that is a colorless, oily liquid with a slightly sweet odor (EPA, 2013).

Di-n-octylphthalate- is a colorless, odorless, oily liquid that doesn’t easily evaporate and is a man-made substance to keep plastics soft (Minimal Risk Levels for Hazardous Substances, 2013).

Fluoranthene- is a polycyclic aromatic hydrocarbon consisting of a benzene unit connected by a five membered ring (ChemSpider, 2014).

Hazardous Materials – Substances that when released are capable of creating harm to people, the environment, and property (National Fire Protection Association [NFPA], 2014, p. 10).

Moisture Barrier – The component of an ensemble element or item that principally prevents the transfer of liquids (National Fire Protection Association, p.10, 2014).

n-Octacosane- is a class of saturated hydrocarbons with a straight or branched chain structure (ChemSpider, 2013)

Naphthalene- is made from crude oil or coal tar and is found in cigarette smoke and car exhaust (NPIC, 2012).

NFPA– National Fire Protection Association, volunteer based organization making standards which develops guidelines related to fire protection and prevention. (Lion Apparel, 2014)

Octicizer®- a plasticizer for pharmaceuticals (Medicine, 2011).

Outer Shell – The outermost component of an ensemble element or item, not including trim, hardware, reinforcing material, pockets, wristlet material, accessories, fittings, or suspension systems (National Fire Protection Association, p. 10, 2014).

Particulates – Finely divided solid matter that is dispersed in air (National Fire Protection Association, p. 14, 2013).

PCB 194- is a part of the group polychlorinated biphenyls (Biomonitoring, 2014).

Pentabromodiphenyl ether- is a brominated flame retardant including BDE 22, 47, 99 and 100 (EPA, 2014).

Pentachlorophenol- is an organochlorine compound used as a pesticide and a disinfectant; a manufactured chemical that does not occur naturally (ASTDR, 2014)

Phenanthrene- is a polycyclic aromatic hydrocarbon composed of three fused benzene rings (ChemSpider, 2011).

Pyrene- is a polycyclic aromatic hydrocarbon and found naturally in the environment but they can also be man-made (EPA, 2011).

Routine Cleaning – The light cleaning of ensembles or ensemble elements performed by the end user without taking the ensembles out of service (National Fire Protection Association, p. 11, 2014).

Sample – The ensemble, element, component, or composite that is conditioned for testing (National Fire Protection Association, p.15, 2013).

Soil/Soiled/Soiling – The accumulation of materials that are not considered hazardous materials, body fluids, or CBRN terrorism agents but that could degrade the performance of the ensemble or ensemble element (National Fire Protection Association [NFPA], 2014, p. 11).

Thermal Barrier – The component of an ensemble element or item that principally provides thermal protection (National Fire Protection Association, p. 11, 2014).

Turnout Gear – The protective clothing used to protect the firefighter.

Appendix B

Table B1

CAS Number of Compounds Identified in Phase II

Substance Identification #	Compound	CAS Number
1	DBDBF	10016-52-1
2	BDE 28	41318-75-6
3	Octicizer®	1241-94-7
4	BDE 47	40088-47-9
5	PCB 194	35694-08-7
6	octacosane	630-02-4
7	BDE 100	189084-64-8
8	BDE 99	32534-81-9
9	BDE 153	68631-49-2
10	anthracene	120-12-7
11	benzo (a) pyrene	50-31-8
12	BzBP	85-68-7
13	Chrysene	218-01-9
14	dimethyl phthalate	131-11-3
15	fluoranthene	206-44-0
16	napthalene	91-20-3
17	di-n-octylphthalate	117-84-0
18	pentachlorophenol	87-86-5
19	phenanthrene	85-01-8
20	Pyrene	129-00-0

(Niosh Pocket Guide to Chemical Hazards, 2010)

Appendix C

Table C1

Data Key

Garment Information	Phase	As listed
	Garment Number	As listed
	Wash History	1- Yes
		2-No
Label Information	Manufacturing #	1-Yes
		2-No
	Shell & Liner Labels Match	1-Yes
		2- No
	Shell Label Integrity	1-Yes
		2- No
	Shell Label Attached	1-Yes
		2- No
	Liner Label Legibility	1-Yes
		2- No
	Liner Label Attached	1-Yes
		2- No
Trim	Trim Securely Attached?	1-Yes
		2- No
	Trim-Damage 1" or Greater	1-Yes
		2- No
Closure Systems	Hook/Loop Missing or Damaged	1-Yes
		2-No
	Hook/Loop Functionality	1-Yes
		2-No
	Hook/Loop Proper Attachment	1-Yes
		2-No

Table C1

Data Key (continued)

Closures System	Zipper-Functionality	1-Yes
		2-No
	Zipper- Corrosion/Damage	1-Yes
		2-No
	Zipper-Proper Attachment	1-Yes
		2-No
	Clasp-Missing or Damaged	1-Yes
		2-No
	Clasp-Functionality	1-Yes
		2-No
	Clasp-Proper Attachment	1-Yes
		2-No
Liner Attachment	Liner Attachment-Missing or Damaged	1-Yes
		2-No
	Liner Attachment- Functionality	1-Yes
		2-No
	Liner Attachment- Corrosion/Damage	1-Yes
		2-No
	Liner Attachment-Proper Attachment	1-Yes
		2-No
Outer Shell, Moisture Barrier, and Thermal Liner Information	Soiling	0-None
		1-Slight
		2-Moderate
		3-Extreme
	Overall Evaluation	0-Extremely Poor
		1-Poor
		2-Fair

Table C1

Data Key (continued)

Outer Shell, Moisture Barrier, and Thermal Liner Information	Spots, Holes, Cuts	1-Yes
		2-No
	Thermal Damage	1-Yes
		2-No
	Seal Tape Secure	1-Yes
		2-No
	Broken Stitches	1-Yes
		2-No
	Discoloration	1-Yes
		2-No
	Change in Material Texture	1-Yes
		2-No
	Change in Material Strength	1-Yes
		2-No
	Knit Wristlet Serviceable	1-Yes
		2-No

Table C2

Visual Assessment Phase I

Garment Information			Label Information					
Phase	Garment	Wash History	Manufacturing #	Compatible Labels	Shell Legibility	Shell Attachment	Liner Legibility	Liner Attachment
I*	1*	2*	1	1*	1*	1*	1*	1*
I	2	2	1	1	1	1	1	1
I	3	2	1	1	1	1	1	1
I	4	2	1	1	1	1	1	1
I	5	2	1	1	1	1	1	1
I	6	2	1	1	1	1	1	1
I	7	2	1	1	1	1	1	1
I	8	2	1	1	1	1	1	1
I	9	2	1	1	1	1	1	1
I	10	2	1	1	1	1	1	1
I	11	2	1	1	1	1	1	1
I	12	2	1	1	1	1	1	1
I	13	2	1	1	1	1	1	1
I	14	2	1	1	1	1	1	1
I	15	2	1	1	1	1	1	1
I	16	2	1	1	1	1	1	1
I	17	2	1	1	1	1	1	1
I	18	2	1	1	1	1	1	1
I	19	2	1	1	1	1	1	1
I	20	2	1	1	1	1	1	1
I	21	2	1	1	1	1	1	1
I	22	2	1	1	1	1	1	1
I	23	2	1	1	1	1	1	1
I	24	2	1	1	1	1	1	1

*Codes are located in the Data Key (Table C1)

Table C2

Visual Assessment of Garments in Phase I- continued

Liner Attachment				
Garment Number	Missing or Damaged	Functionality	Corrosion/Damage	Proper Attachment
1*	2	1	2	1
2	2	1	2	1
3	2	1	2	1
4	2	1	2	1
5	2	1	2	1
6	2	1	2	1
7	2	1	2	1
8	2	1	2	1
9	2	1	2	1
10	2	1	2	1
11	2	1	2	1
12	2	1	2	1
13	2	1	2	1
14	2	1	2	1
15	2	1	2	1
16	2	1	2	1
17	2	1	2	1
18	2	1	2	1
19	2	1	2	1
20	2	1	2	1
21	2	1	2	1
22	2	1	2	1
23	2	1	2	1
24	2	1	2	1

*Codes are located in the Data Key (Table C1)

Table C2

Visual Assessment of Garments in Phase I- continued

Closures					
Garment Number	Hook/Loop Missing or Damaged	Hook/Loop Functionality	Hook/Loop Properly Attached	Zipper-Missing/ Damaged	Zipper- Functionality
1*	2	1	1	2	1
2	2	1	1	2	1
3	2	1	1	2	1
4	2	1	1	2	1
5	2	1	1	2	1
6	2	1	1	2	1
7	2	1	1	2	1
8	2	1	1	2	1
9	2	1	1	2	1
10	2	1	1	2	1
11	2	1	1	2	1
12	2	1	1	2	1
13	2	1	1	2	1
14	2	1	1	2	1
15	2	1	1	2	1
16	2	1	1	2	1
17	2	1	1	2	1
18	2	1	1	2	1
19	2	1	1	2	1
20	2	1	1	2	1
21	2	1	1	2	1
22	2	1	1	2	1
23	2	1	1	2	1
24	2	1	1	2	1

*Codes are located in the Data Key (Table C1)

Table C2

Visual Assessment Phase I- continued

Closures						
Garment Number	Zipper-Corrosion/Damage	Zipper-Proper Attachment	Clasp-Missing or Damaged	Clasp-Functionality	Clasp-Corrosion/Damage	Clasp-Proper Attachment
1*	2	1	2	1	2	1
2	2	1	2	1	2	1
3	2	1	2	1	2	1
4	2	1	2	1	2	1
5	2	1	2	1	2	1
6	2	1	2	1	2	1
7	2	1	2	1	2	1
8	2	1	2	1	2	1
9	2	1	2	1	2	1
10	2	1	2	1	2	1
11	2	1	2	1	2	1
12	2	1	2	1	2	1
13	2	1	2	1	2	1
14	2	1	2	1	2	1
15	2	1	2	1	2	1
16	2	1	2	1	2	1
17	2	1	2	1	2	1
18	2	1	2	1	2	1
19	2	1	2	1	2	1
20	2	1	2	1	2	1
21	2	1	2	1	2	1
22	2	1	2	1	2	1
23	2	1	2	1	2	1
24	2	1	2	1	2	1

*Codes are located in the Data Key (Table C1)

Table C2

Visual Assessment Phase I- continued

Outer Shell									
Garment Number	Soiling	Overall Evaluation	Spots, Holes, Cuts	Thermal Damage	Broken Stitches	Discoloration	Change in Material Texture	Change in Material Strength	Knit Wristlet Serviceable?
1*	3	1	1	1	1	1	1	-	1
2	3	2	2	2	2	1	1	-	1
3	3	2	1	1	1	1	1	-	1
4	3	1	1	1	1	1	1	-	1
5	3	1	1	1	1	1	1	-	1
6	3	1	1	1	1	1	1	-	1
7	3	1	1	2	1	1	1	-	1
8	3	1	2	2	1	1	1	-	1
9	3	1	2	1	1	1	1	-	1
10	3	1	2	2	1	1	1	-	1
11	3	1	1	1	1	1	1	-	1
12	3	1	1	1	2	1	1	-	1
13	3	2	1	1	2	1	1	-	1
14	3	1	1	1	1	1	1	-	1
15	3	1	1	1	2	1	1	-	1
16	3	1	1	1	1	1	1	-	1
17	3	1	1	1	2	1	1	-	1
18	3	1	1	1	2	1	1	-	1
19	3	1	1	2	2	1	1	-	1
20	3	1	2	2	1	1	1	-	1
21	3	1	1	2	1	1	1	-	1
22	3	1	1	2	1	1	1	-	1
23	3	2	1	1	2	1	1	-	1
24	3	1	2	1	1	1	1	-	1

*Codes are located in the Data Key (Table C1)

Table C2

Visual Assessment Phase I- continued

Garment Number	Moisture Barrier							
	Soiling	Overall Evaluation	Spots, Holes, Cuts	Thermal Damage	Seal Tape Secure?	Discoloration	Change in Material Texture?	Change in Material Strength?
1*	3	2	1	1	1	1	1	-
2	3	3	1	1	1	1	1	-
3	3	2	1	1	1	1	1	-
4	3	2	1	1	1	1	1	-
5	2	2	1	1	1	1	1	-
6	3	2	1	1	1	1	1	-
7	3	2	1	1	1	1	1	-
8	3	3	2	1	1	1	1	-
9	3	2	1	1	1	1	1	-
10	2	2	1	1	1	1	1	-
11	2	2	1	1	1	1	1	-
12	2	3	1	1	1	1	2	-
13	3	2	1	1	1	1	2	-
14	3	2	1	1	1	1	2	-
15	3	2	1	1	1	1	1	-
16	3	3	2	1	1	1	1	-
17	2	2	2	1	1	1	1	-
18	2	3	1	1	1	1	1	-
19	2	2	2	1	1	1	1	-
20	2	2	2	1	1	1	1	-
21	2	2	2	1	1	1	2	-
22	3	2	1	1	1	1	1	-
23	2	2	1	1	1	1	1	-
24	3	2	1	1	1	1	1	-

*Codes are located in the Data Key (Table C1)

Table C2

Visual Assessment Phase I- continued

Garment Number	Thermal Liner							
	Soiling	Overall Evaluation	Spots, Holes, Cuts	Thermal Damage	Broken Stitches-Quilting	Discoloration	Change in Material Texture?	Change in Material Strength?
1*	3	1	1	1	1	1	-	1
2	2	2	1	1	1	1	-	1
3	2	2	1	1	1	1	-	1
4	2	2	1	1	1	1	-	1
5	2	1	1	1	1	1	-	1
6	3	1	1	1	1	1	-	1
7	3	1	1	1	1	1	-	1
8	3	1	1	1	1	1	-	1
9	3	2	1	1	1	1	-	1
10	2	1	1	1	1	1	-	1
11	2	1	1	1	1	1	-	1
12	2	1	1	1	1	1	-	1
13	2	1	1	1	1	1	-	1
14	3	1	1	1	1	1	-	1
15	3	1	1	1	1	1	-	1
16	3	1	1	1	1	1	-	1
17	3	2	1	1	1	1	-	1
18	3	2	1	1	1	1	-	1
19	3	2	1	1	1	1	-	1
20	3	2	1	1	1	1	-	1
21	3	2	1	1	1	1	-	1
22	3	1	1	1	1	1	-	1
23	3	1	1	1	1	1	-	1
24	3	1	1	1	1	1	-	1

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II

Garment Information			Label Information					
Phase	Garment	Wash History	Manufacturing #	Compatible Labels	Shell Legibility	Shell Attachment	Liner Legibility	Liner Attachment
II	25	1	1	1*	1*	1*	1*	1*
II	26	1	1	1	1	1	1	1
II	27	1	1	1	1	1	1	1
II	28	1	1	1	1	1	1	1
II	29	1	1	1	1	1	1	1
II	30	1	1	1	1	1	1	1
II	31	1	1	1	1	1	1	1
II	32	1	1	1	1	1	1	1
II	33	1	1	1	1	1	1	1
II	34	1	1	1	1	1	1	1
II	35	1	1	1	1	1	1	1
II	36	1	1	1	1	1	1	1
II	37	1	1	1	1	1	1	1
II	38	1	1	1	1	1	1	1
II	39	1	1	1	1	1	1	1
II	40	1	1	1	1	1	1	1
II	41	1	1	1	1	1	1	1
II	42	1	1	1	1	1	1	1
II	43	1	1	1	1	1	1	1
II	44	1	1	1	1	1	1	1
II	45	1	1	1	1	1	1	1
II	46	1	1	1	1	1	1	1
II	47	1	1	1	1	1	1	1
II	48	1	1	1	1	1	1	1
II	49	1	1	1	1	1	1	1
II	50	1	1	1	1	1	1	1

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Garment Information			Label Information					
Phase	Garment	Wash History	Man. #	Labels	Shell Legible	Shell Attach.	Liner Legible	Liner Attach.
II	51	1	1	1	1	1	1	1
II	52	1	1	1	1	1	1	1
II	53	1	1	1	1	1	1	1
II	54	1	1	1	1	1	1	1
II	55	1	1	1	1	1	1	1
II	56	1	1	1	1	1	1	1
II	57	1	1	1	1	1	1	1
II	58	1	1	1	1	1	1	1
II	59	1	1	1	1	1	1	1
II	60	1	1	1	1	1	1	1
II	61	1	1	1	1	1	1	1
II	62	1	1	1	1	1	1	1
II	63	1	1	1	1	1	1	1
II	64	1	1	1	1	1	1	1
II	65	1	1	1	1	1	1	1
II	66	1	1	1	1	1	1	1
II	67	1	1	1	1	1	1	1
II	68	1	1	1	1	1	1	1
II	69	1	1	1	1	1	1	1
II	70	1	1	1	1	1	1	1
II	71	1	1	1	1	1	1	1
II	72	1	1	1	1	1	1	1
II	73	1	1	1	1	1	1	1
II	74	1	1	1	1	1	1	1
II	75	1	1	1	1	1	1	1
II	76	1	1	1	1	1	1	1
II	77	1	1	1	1	1	1	1
II	78	1	1	1	1	1	1	1
II	79	1	1	1	1	1	1	1
II	80	1	1	1	1	1	1	1

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Liner Attachment				
Garment Number	Missing or Damaged	Functionality	Corrosion/ Damage	Proper Attachment
25	2	1	2	1
26	2	1	2	1
27	2	1	2	1
28	2	1	2	1
29	2	1	2	1
30	2	1	2	1
31	2	1	2	1
32	2	1	2	1
33	2	1	1	1
34	2	1	1	1
35	2	1	2	1
36	2	1	2	1
37	2	1	2	1
38	2	1	2	1
39	2	1	2	1
40	2	1	2	1
41	2	1	2	1
42	2	1	2	1
43	2	1	2	1
44	2	1	2	1
45	2	1	2	1
46	2	1	2	1
47	2	1	2	1
48	2	1	2	1
49	2	1	2	1
50	2	1	1	1

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Liner Attachment				
Garment Number	Missing or Damaged	Functionality	Corrosion/ Damage	Proper Attachment
51	2	1	2	1
52	2	1	2	1
53	2	1	2	1
54	2	1	2	1
55	2	1	2	1
56	2	1	2	1
57	2	1	2	1
58	2	1	2	1
59	2	1	2	1
60	2	1	2	1
61	2	1	2	1
62	2	1	2	1
63	2	1	2	1
64	2	1	2	1
65	2	1	2	1
66	2	1	2	1
67	2	1	2	1
68	2	1	2	1
69	2	1	2	1
70	2	1	2	1
71	2	1	2	1
72	2	1	2	1
73	2	1	2	1
74	2	1	2	1
75	2	1	2	1
76	2	1	2	1
77	2	1	2	1
78	2	1	2	1
79	2	1	2	1
80	2	1	2	1

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Closures					
Garment Number	Hook/Loop Missing or Damaged	Hook/Loop Functionality	Hook/Loop Properly Attached	Zipper-Missing/ Damaged	Zipper-Functionality
25	2	1	1	2	1
26	2	1	1	2	1
27	2	1	1	2	1
28	2	1	1	2	1
29	2	1	1	2	1
30	2	1	1	2	1
31	2	1	1	2	1
32	2	1	1	2	1
33	2	1	1	2	1
34	2	1	1	2	1
35	2	1	1	2	1
36	2	1	1	2	1
37	2	1	1	2	1
38	2	1	1	2	1
39	2	1	1	2	1
40	2	1	1	2	1
41	2	1	1	2	1
42	2	1	1	2	1
43	2	1	1	2	1
44	2	1	1	2	1
45	2	1	1	2	1
46	2	1	1	2	1
47	2	1	1	2	1
48	2	1	1	2	1
49	2	1	1	2	1
50	2	1	1	2	1

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Closures					
Garment Number	Hook/Loop Missing/Damaged	Hook/Loop Functional	Hook/Loop Attached	Zipper-Damaged	Zipper-Function
51	2	1	1	2	1
52	2	1	1	2	1
53	2	1	1	2	1
54	2	1	1	2	1
55	2	1	1	2	1
56	2	1	1	2	1
57	2	1	1	2	1
58	2	1	1	2	1
59	2	1	1	2	1
60	2	1	1	2	1
61	2	1	1	2	1
62	2	1	1	2	1
63	2	1	1	2	1
64	2	1	1	2	1
65	2	1	1	2	1
66	2	1	1	2	1
67	2	1	1	2	1
68	2	1	1	2	1
69	2	1	1	2	1
70	2	1	1	2	1
71	2	1	1	2	1
72	2	1	1	2	1
73	2	1	1	2	1
74	2	1	1	2	1
75	2	1	1	2	1
76	2	1	1	2	1
77	2	1	1	2	1
78	2	1	1	2	1
79	2	1	1	2	1
80	2	1	1	2	1

Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Closures						
Garment Number	Zipper-Corrosion/ Damage	Zipper-Proper Attachment	Clasp-Missing or Damaged	Clasp-Functionality	Clasp-Corrosion/Damage	Clasp-Proper Attachment
25	2	1	2	1	2	1
26	2	1	2	1	2	1
27	2	1	2	1	2	1
28	2	1	2	1	2	1
29	2	1	2	1	2	1
30	2	1	2	1	2	1
31	2	1	2	1	2	1
32	2	1	2	1	2	1
33	2	1	2	1	2	1
34	2	1	2	1	2	1
35	2	1	2	1	2	1
36	2	1	2	1	2	1
37	2	1	2	1	2	1
38	2	1	2	1	2	1
39	2	1	2	1	2	1
40	2	1	2	1	2	1
41	2	1	2	1	2	1
42	2	1	2	1	2	1
43	2	1	2	1	2	1
44	2	1	2	1	2	1
45	2	1	2	1	2	1
46	2	1	2	1	2	1
47	2	1	2	1	2	1
48	2	1	2	1	2	1
49	2	1	2	1	2	1
50	2	1	2	1	2	1

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Closures						
Garment Number	Zipper- Corrosion/ Damage	Zipper- Proper Attachment	Clasp- Missing or Damaged	Clasp- Functional	Clasp- Corrosion/ Damage	Clasp- Proper Attachment
51	2	1	2	1	2	1
52	2	1	2	1	2	1
53	2	1	2	1	2	1
54	2	1	2	1	2	1
55	2	1	2	1	2	1
56	2	1	2	1	2	1
57	2	1	2	1	2	1
58	2	1	2	1	2	1
59	2	1	2	1	2	1
60	2	1	2	1	2	1
61	2	1	2	1	2	1
62	2	1	2	1	2	1
63	2	1	2	1	2	1
64	2	1	2	1	2	1
65	2	1	2	1	2	1
66	2	1	2	1	2	1
67	2	1	2	1	2	1
68	2	1	2	1	2	1
69	2	1	2	1	2	1
70	2	1	2	1	2	1
71	2	1	2	1	2	1
72	2	1	2	1	2	1
73	2	1	2	1	2	1
74	2	1	2	1	2	1
75	2	1	2	1	2	1
76	2	1	2	1	2	1
77	2	1	2	1	2	1
78	2	1	2	1	2	1
79	2	1	2	1	2	1
80	2	1	2	1	2	1

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Outer Shell									
Garment Number	Soiling	Overall Evaluation	Spots, Holes, Cuts	Thermal Damage	Broken Stitches	Discoloration	Change in Material Texture	Change in Material Strength	Knit Wristlet Serviceable?
25	3	2	1	2	1	1	1	-	1
26	3	2	2	2	1	1	2	-	1
27	3	2	2	2	1	1	2	-	1
28	3	2	2	2	1	1	2	-	1
29	2	2	1	2	1	1	2	-	1
30	3	2	1	2	1	1	2	-	1
31	3	2	1	2	1	1	1	-	1
32	3	2	1	1	1	1	1	-	1
33	3	1	1	1	1	1	1	-	1
34	2	2	1	1	1	1	1	-	1
35	2	2	1	1	1	1	1	-	1
36	2	2	2	1	1	1	2	-	1
37	3	2	2	1	1	1	2	-	1
38	3	2	2	1	1	1	2	-	1
39	3	2	2	1	1	1	2	-	1
40	3	2	1	2	1	1	2	-	1
41	2	2	1	2	1	1	1	-	1
42	2	2	1	2	1	1	1	-	1
43	2	2	2	2	1	1	1	-	1
44	2	2	1	2	1	1	1	-	1
45	2	2	1	1	1	1	1	-	1
46	3	2	2	2	1	1	1	-	1
47	2	1	1	1	1	1	1	-	1
48	3	1	1	1	1	1	1	-	1
49	3	1	1	2	1	1	1	-	1
50	3	1	1	2	1	1	2	-	1
51	3	2	2	2	1	1	1	-	1
52	3	2	2	1	1	1	2	-	1

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Outer Shell									
Garment Number	Soiling	Overall Evaluation	Spots, Holes, Cuts	Thermal Damage	Broken Stitches	Discoloration	Change in Material Texture	Change in Material Strength	Knit Wristlet Serviceable
53	2	2	2	1	1	1	2	-	1
54	3	2	2	1	1	1	2	-	1
55	3	2	2	1	1	1	2	-	1
56	3	2	2	1	1	1	2	-	1
57	3	2	2	2	1	1	2	-	1
58	2	2	1	2	1	1	2	-	1
59	2	2	1	2	1	1	1	-	1
60	2	2	1	2	1	1	1	-	1
61	3	2	1	2	1	1	1	-	1
62	3	2	2	2	1	1	1	-	1
63	3	2	1	2	1	1	1	-	1
64	3	2	2	2	1	1	1	-	1
65	2	2	1	2	1	1	1	-	1
66	2	2	1	2	1	1	1	-	1
67	2	2	1	2	1	1	1	-	1
68	2	2	2	2	1	1	2	-	1
69	2	2	2	2	1	1	2	-	1
70	3	2	2	2	1	1	2	-	1
71	2	2	2	2	1	1	2	-	1
72	3	2	2	2	1	1	2	-	1
73	3	2	2	2	1	1	2	-	1
74	3	2	2	2	1	1	2	-	1
75	3	2	2	2	1	1	2	-	1
76	3	2	2	2	1	1	2	-	1
77	3	2	2	2	1	1	2	-	1
78	3	2	2	2	1	1	1	-	1
79	3	2	2	2	1	1	2	-	1
80	3	2	2	2	1	1	1	-	1

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Garment Number	Moisture Barrier							
	Soiling	Overall Evaluation	Spots, Holes, Cuts	Thermal Damage	Seal Tape Secure?	Discoloration	Change in Material Texture?	Change in Material Strength?
25	3	1	1	2	1	1	2	-
26	3	1	1	2	1	1	2	-
27	3	1	1	2	1	1	2	-
28	3	1	1	2	1	1	1	-
29	2	2	1	2	1	1	1	-
30	3	1	1	2	1	1	1	-
31	3	1	1	2	1	1	1	-
32	3	1	1	2	1	1	1	-
33	3	1	1	2	1	1	2	-
34	2	2	1	2	1	1	1	-
35	2	2	1	2	1	1	1	-
36	2	2	1	1	1	1	1	-
37	3	1	1	2	1	1	1	-
38	3	1	1	2	1	1	1	-
39	3	1	1	2	1	1	1	-
40	3	1	1	2	1	1	1	-
41	2	2	1	1	1	1	1	-
42	2	2	1	2	1	1	1	-
43	2	2	1	2	1	1	1	-
44	2	2	1	2	1	1	1	-
45	2	2	1	2	1	1	1	-
46	3	1	1	2	1	1	1	-
47	2	1	1	2	1	1	2	-
48	3	1	1	2	1	1	2	-
49	3	1	1	2	1	1	2	-
50	2	2	1	2	1	1	1	-
51	3	1	1	1	1	1	2	-
52	3	2	1	2	1	1	2	-

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Garment Number	Moisture Barrier							
	Soiling	Overall Evaluation	Spots, Holes, Cuts	Thermal Damage	Seal Tape Secure?	Discoloration	Change in Material Texture	Change in Material Strength
53	2	2	1	2	1	1	2	-
54	3	1	1	2	1	1	2	-
55	3	1	1	2	1	1	2	-
56	3	1	1	2	1	1	2	-
57	3	1	1	2	1	1	2	-
58	3	2	1	2	1	1	1	-
59	3	2	1	2	1	1	1	-
60	3	2	1	2	1	1	1	-
61	3	2	1	2	1	1	1	-
62	3	2	1	2	1	1	1	-
63	3	1	1	2	1	1	2	-
64	3	1	1	2	1	1	2	-
65	3	2	1	2	1	1	2	-
66	3	2	1	2	1	1	2	-
67	2	1	1	2	1	1	1	-
68	3	1	1	2	1	1	1	-
69	3	1	1	2	1	1	1	-
70	3	1	1	2	1	1	1	-
71	3	2	1	2	1	1	1	-
72	2	2	1	2	1	1	1	-
73	2	2	1	2	1	1	2	-
74	2	2	1	2	1	1	1	-
75	3	2	1	2	1	1	2	-
76	3	1	1	2	1	1	1	-
77	3	1	1	2	1	1	2	-
78	3	1	1	2	1	1	2	-
79	2	2	1	2	1	1	2	-
80	2	2	1	2	1	1	1	-

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Garment Number	Thermal Liner							
	Soiling	Overall Evaluation	Spots, Holes, Cuts	Thermal Damage	Broken Stitches-Quilting	Discoloration	Change in Material Texture	Change in Material Strength
25	3	1	1	2	1	1	2	-
26	3	1	1	2	1	1	2	-
27	3	1	1	2	1	1	2	-
28	3	1	1	2	1	1	1	-
29	2	2	1	2	1	1	1	-
30	3	1	1	2	1	1	1	-
31	3	1	1	2	1	1	1	-
32	3	1	1	2	1	1	1	-
33	3	1	1	2	1	1	2	-
34	2	2	1	2	1	1	1	-
35	2	2	1	2	1	1	1	-
36	2	2	1	2	1	1	1	-
37	3	1	1	2	1	1	1	-
38	3	1	1	2	1	1	1	-
39	3	1	1	2	1	1	1	-
40	3	1	1	2	1	1	1	-
41	2	2	1	2	1	1	1	-
42	2	2	1	2	1	1	1	-
43	2	2	1	2	1	1	1	-
44	2	2	1	2	1	1	1	-
45	2	2	1	2	1	1	1	-
46	3	1	1	2	1	1	1	-
47	2	1	1	2	1	1	2	-
48	3	1	1	2	1	1	2	-
49	3	1	1	2	1	1	2	-
50	2	2	1	2	1	1	1	-
51	3	1	1	2	1	1	2	-
52	3	2	1	2	1	1	2	-

*Codes are located in the Data Key (Table C1)

Table C3

Visual Assessment Phase II-continued

Garment Number	Thermal Liner							
	Soiling	Overall Evaluation	Spots, Holes, Cuts	Thermal Damage	Broken Stitches-Quilting	Discoloration	Change in Material Texture?	Change in Material Strength?
53	2	2	1	2	1	1	2	-
54	3	1	1	2	1	1	2	-
55	3	1	1	2	1	1	2	-
56	3	1	1	2	1	1	2	-
57	3	1	1	2	1	1	2	-
58	3	2	1	2	1	1	1	-
59	3	2	1	2	1	1	1	-
60	3	2	1	2	1	1	1	-
61	3	2	1	2	1	1	1	-
62	3	2	1	2	1	1	1	-
63	3	1	1	2	1	1	2	-
64	3	1	1	2	1	1	2	-
65	3	2	1	2	1	1	2	-
66	3	2	1	2	1	1	2	-
67	2	1	1	2	1	1	1	-
68	3	1	1	2	1	1	1	-
69	3	1	1	2	1	1	1	-
70	3	1	1	2	1	1	1	-
71	3	2	1	2	1	1	1	-
72	2	2	1	2	1	1	1	-
73	2	2	1	2	1	1	2	-
74	2	2	1	2	1	1	1	-
75	3	2	1	2	1	1	2	-
76	3	1	1	2	1	1	1	-
77	3	1	1	2	1	1	2	-
78	3	1	1	2	1	1	2	-
79	2	2	1	2	1	1	2	-
80	2	2	1	2	1	1	1	-

*Codes are located in the Data Key (Table C1)

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VITA

Tabitha Nicole Huston was born in Martin, Kentucky and raised by her grandparents in rural eastern Kentucky. Tabitha attended Pike County Central High School and graduated with honors in May of 2005. From there, she attended the University of Kentucky as the first in her family to attend college. Tabitha earned a Bachelor of Science in Merchandising, Apparel and Textiles and a minor in Business upon graduation in May of 2011. Tabitha worked for a small business in Lexington, Kentucky post-graduation where she built her skill set within the industry and realized she had a continued growing passion for textiles; with that passion she began her graduate career at the University of Kentucky where she was a textile lab technician/supervisor and a teaching assistant. Tabitha was awarded a graduate research assistantship in 2013 and a fellowship in 2014.

Tabitha Nicole Huston